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GRB-Supernova connection and supernova shock breakout

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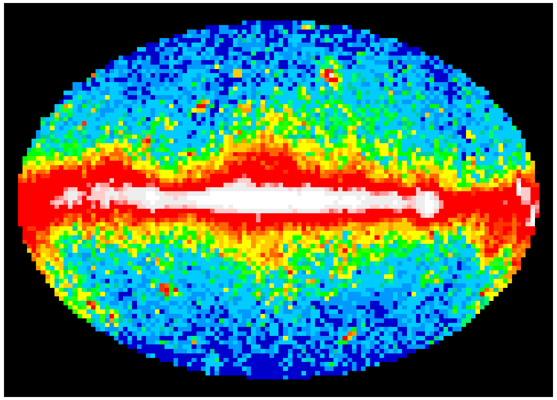
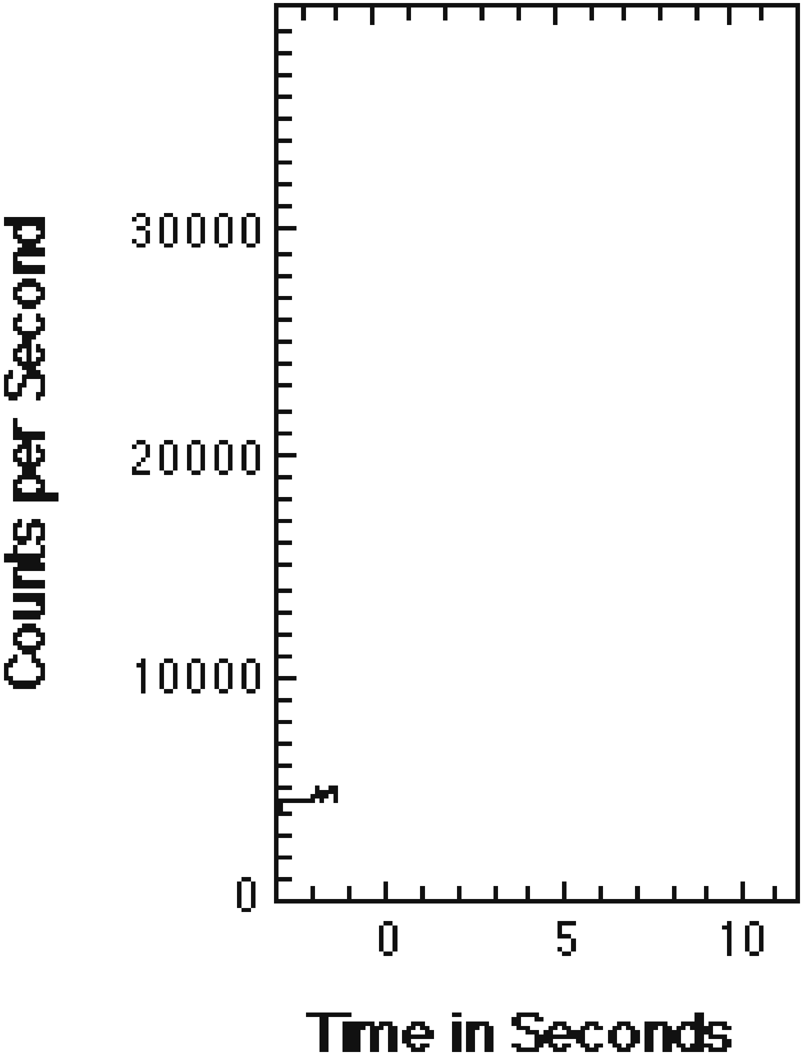
Outline

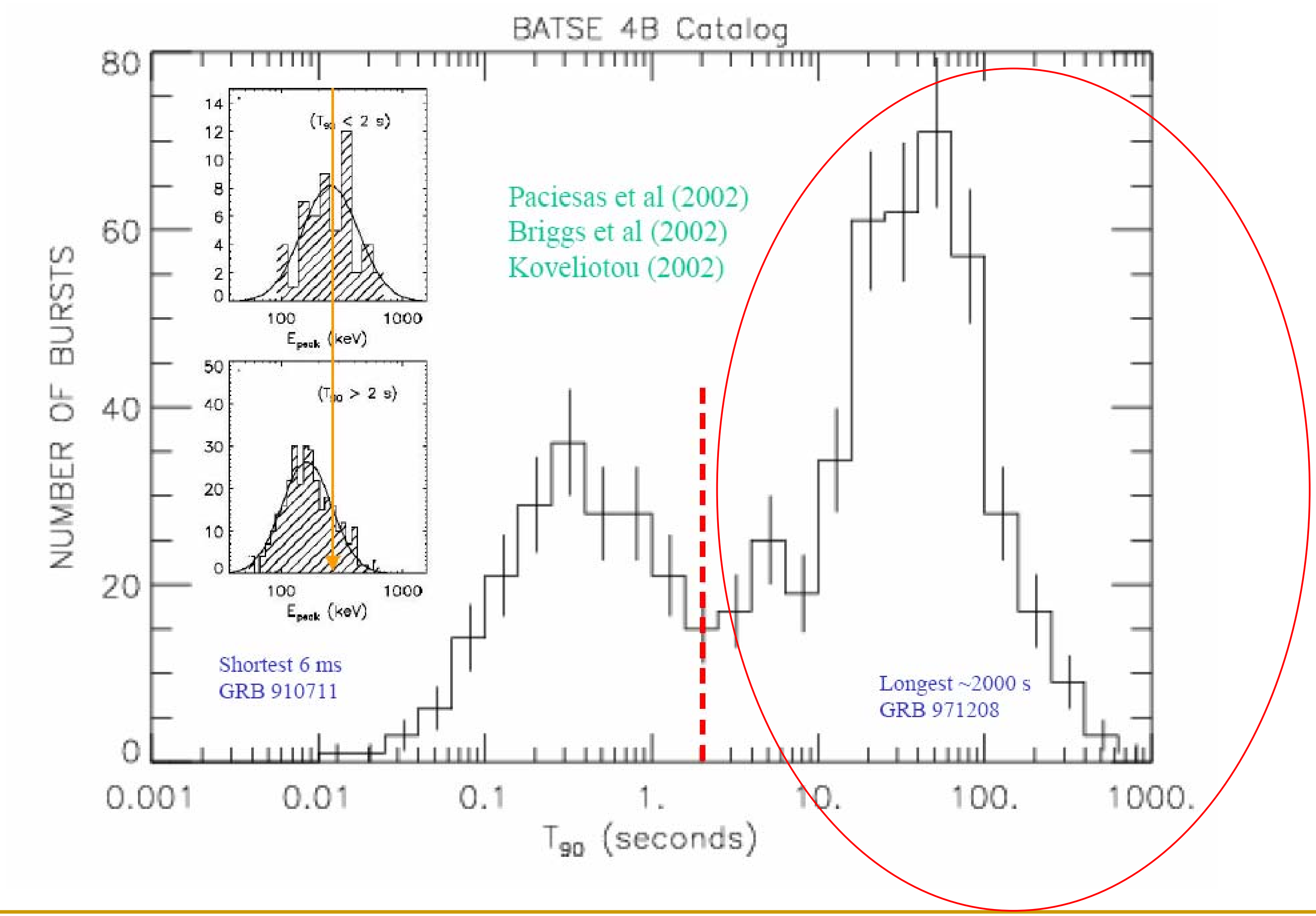
- Observation facts and theoretical aspects of GRB-Supernova connection
- Low-luminosity GRBs and hypernova shock breakout
- X-ray outburst associated with ordinary SN 2008D –SN shock breakout model

One GRB event



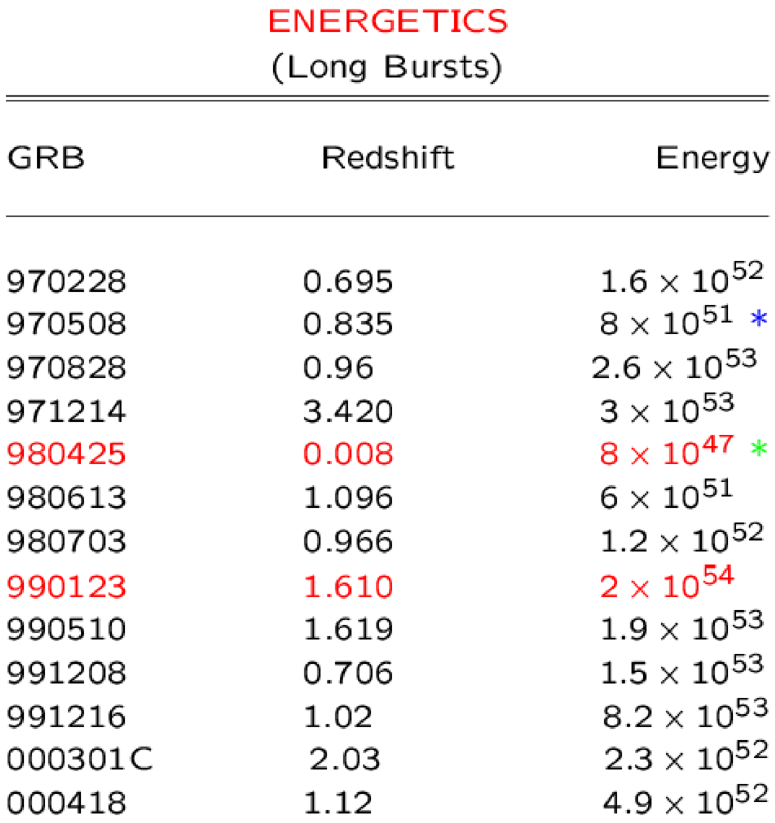


Bi-mode duration distribution



will focus on this

GRB isotropic energy with measured redshift



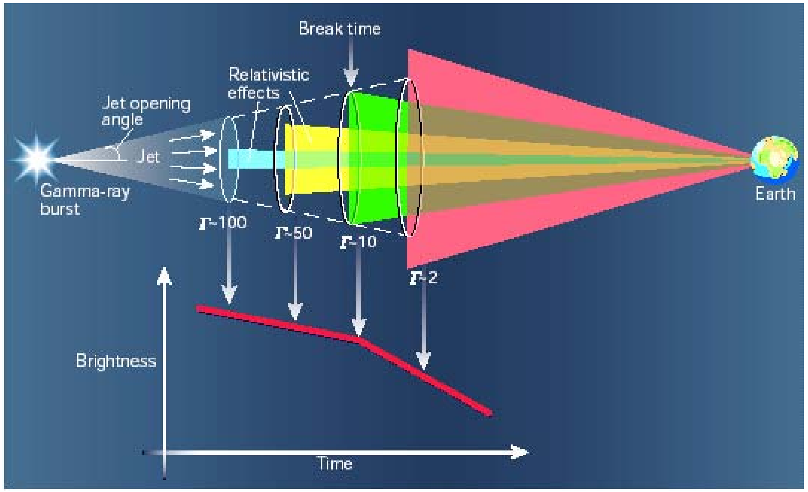
ENERGETICS

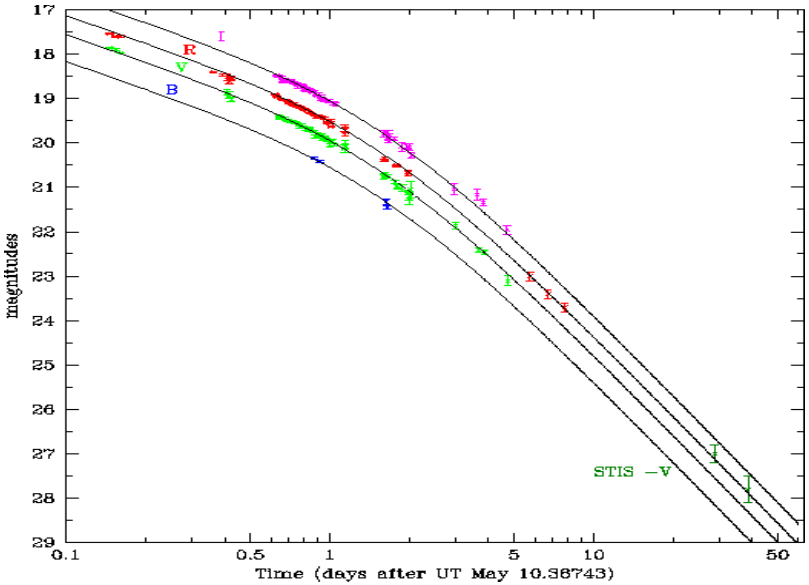
(Long Bursts)

GRB	Redshift	Energy
970228	0.695	1.6×10^{52}
970508	0.835	8×10^{51} *
970828	0.96	2.6×10^{53}
971214	3.420	3×10^{53}
980425	0.008	8×10^{47} *
980613	1.096	6×10^{51}
980703	0.966	1.2×10^{52}
990123	1.610	2×10^{54}
990510	1.619	1.9×10^{53}
991208	0.706	1.5×10^{53}
991216	1.02	8.2×10^{53}
000301C	2.03	2.3×10^{52}
000418	1.12	4.9×10^{52}

The typical energy is 10^{53} erg or about 5% of the mass of the sun turned to pure energy according to $E = mc^2$

Jet





GRB990510

当 Γ~1/θ, 光变曲线出现拐折

GRB beam-corrected energy- comparable to SN

20

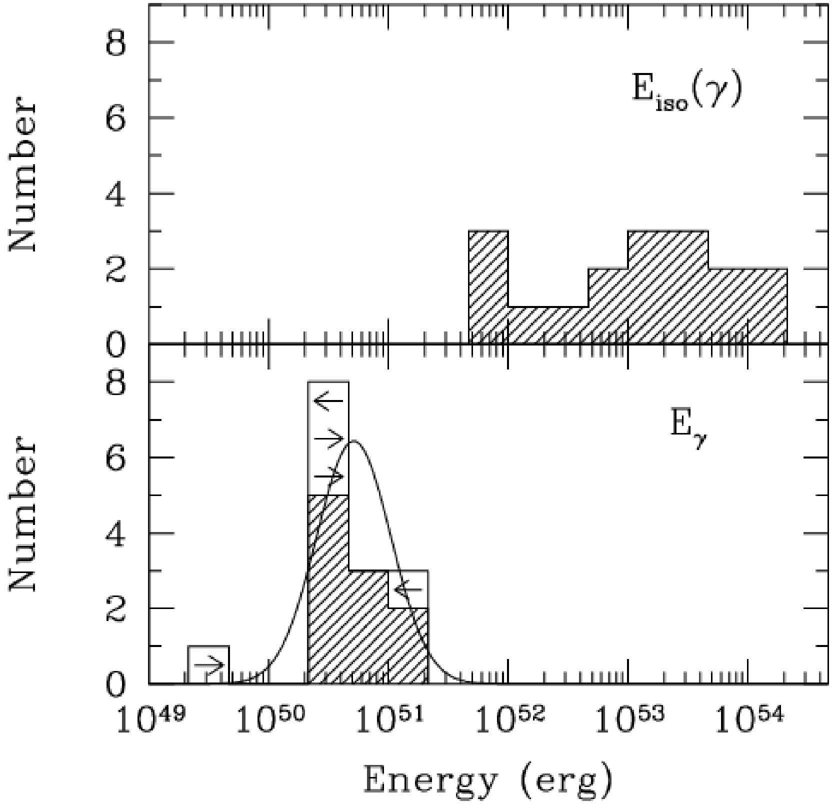


Figure 3. The distribution of the apparent isotropic γ-ray burst energy of GRBs with known redshifts (top) versus the geometry-corrected energy for those GRBs whose afterglows exhibit the signature of a non-isotropic outflow (bottom). The mean isotropic equivalent energy $\langle E_{iso}(\gamma)\rangle$ for 17 GRBs is 110×10^{51} erg with a 1-σ spreading of a multiplicative factor of 6.2. In estimating the mean geometry-corrected energy $\langle E_\gamma\rangle$ we applied the Bayesian inference formalism[60] and modified to handle datasets containing upper and lower limits.[61] Arrows are plotted for five GRBs to indicate upper or lower limits to the geometry-corrected energy. The value of $\langle \log E_\gamma\rangle$ is 50.71 ± 0.10 (1σ) or equivalently, the mean geometry-corrected energy $\langle E_\gamma\rangle$ for 15 GRBs is 0.5×10^{51} erg. The standard deviation in $\log E_\gamma$ is $0.31^{+0.09}_{-0.06}$, or a 1-σ spread corresponding to a multiplicative factor of 2.0.

Frail et al. ApJL, (2001), astro/ph 0102282

Despite their large inferred brightness, it is increasingly believed that GRBs are not inherently much more powerful than supernovae.

See also: Freedman & Waxman,
ApJ, 547, 922 (2001)

Bloom, Frail, & Sari
AJ, 121, 2879 (2001)

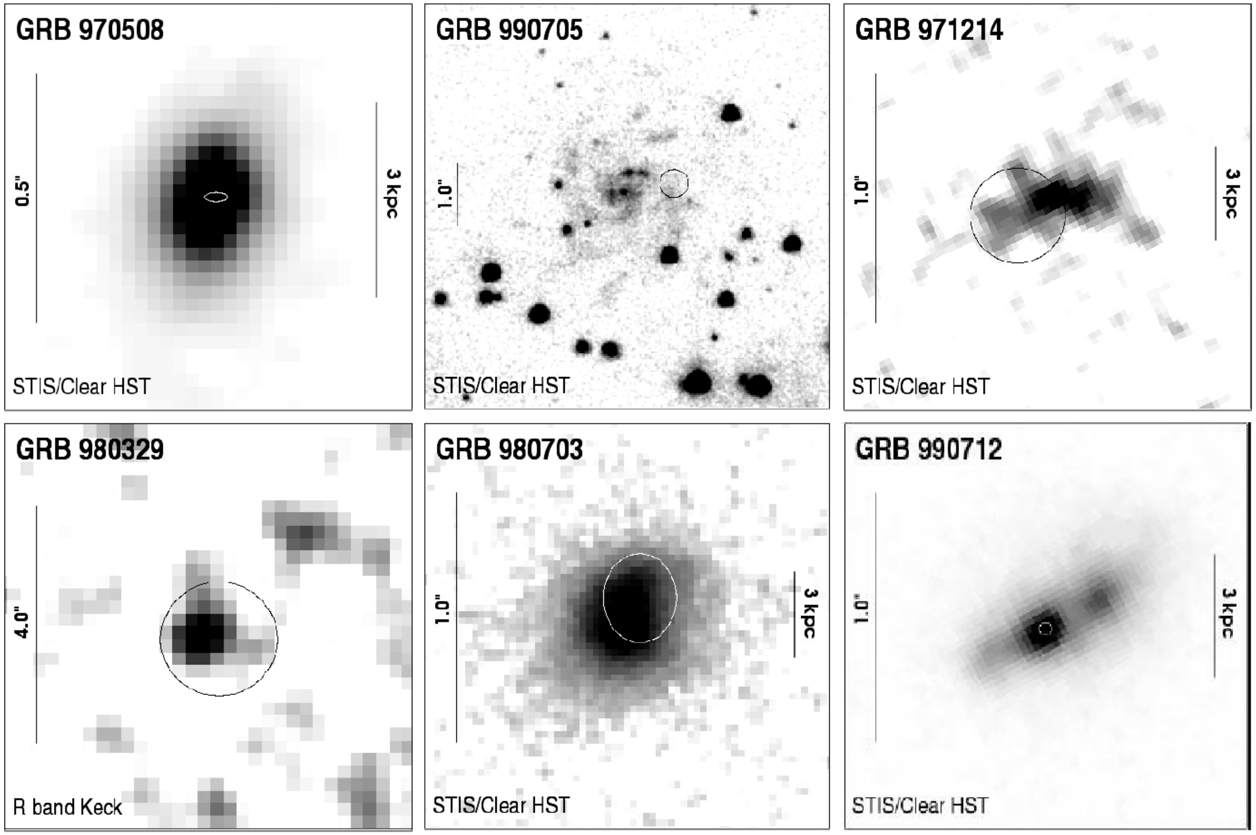
Piran et al. astro/ph 0108033

Panaitescu & Kumar,
ApJL, 560, L49 (2000)

Observational evidence for GRB-SN connection: I

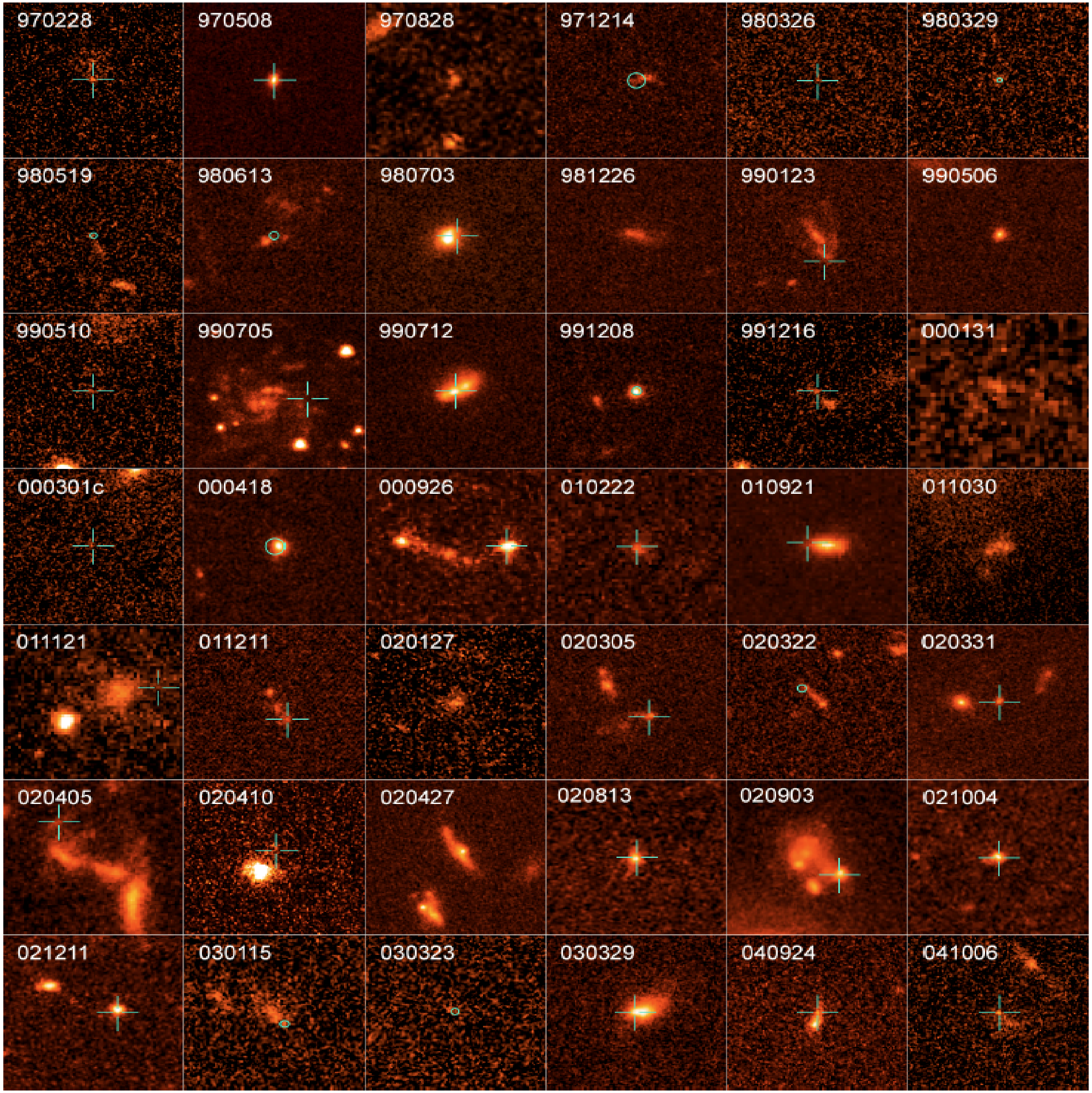
Long GRBs

Location of GRBs Within Their Host Galaxies



Djorgovski et al (2002)

almost always galaxies experiencing an unusual rate of star formation



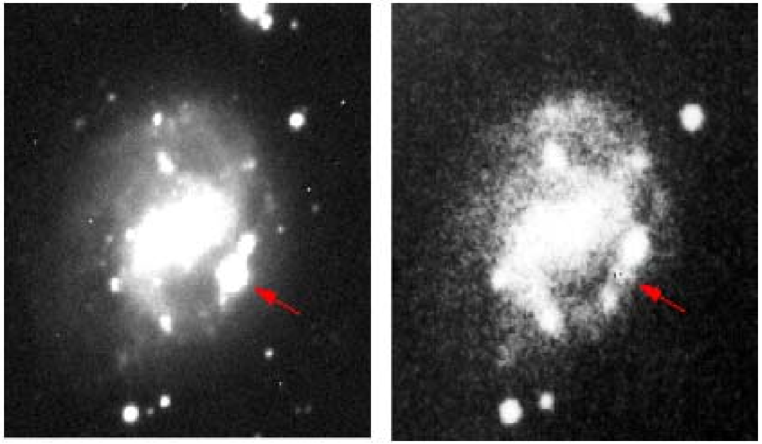
Fruchter et al. (2006)

1. ***Long-duration*** *GRBs are found in star-forming galaxies.*

2. *Their location within those galaxies is associated with the light with a tighter correlation than even core-collapse supernovae.*

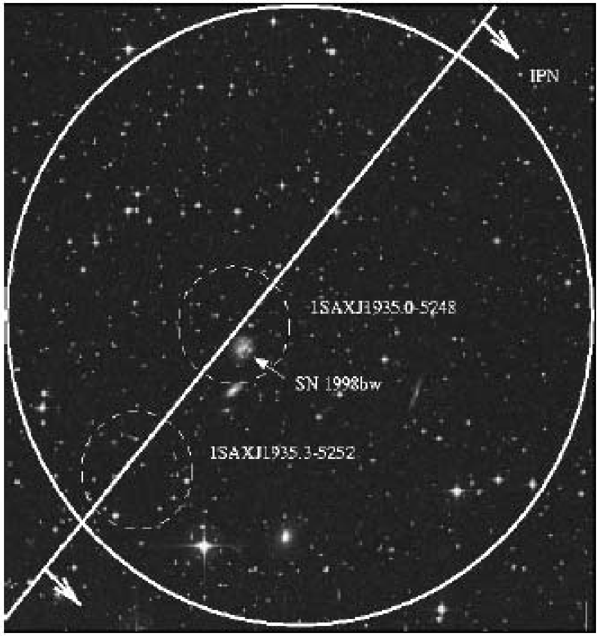
Observational evidence for GRB-SN connection: II

SN 1998bw/GRB 980425



NTT image (May 1, 1998) of SN 1998bw in the barred spiral galaxy ESO 184-G82 [Galama et al, A&A S, 138, 465, (1999)]

Type Ic supernova, d = 40 Mpc
Modeled as the 3 x 10^{52} erg explosion
of a massive CO star
(Iwamoto et al 1998; Woosley, Eastman, & Schmidt 1999)

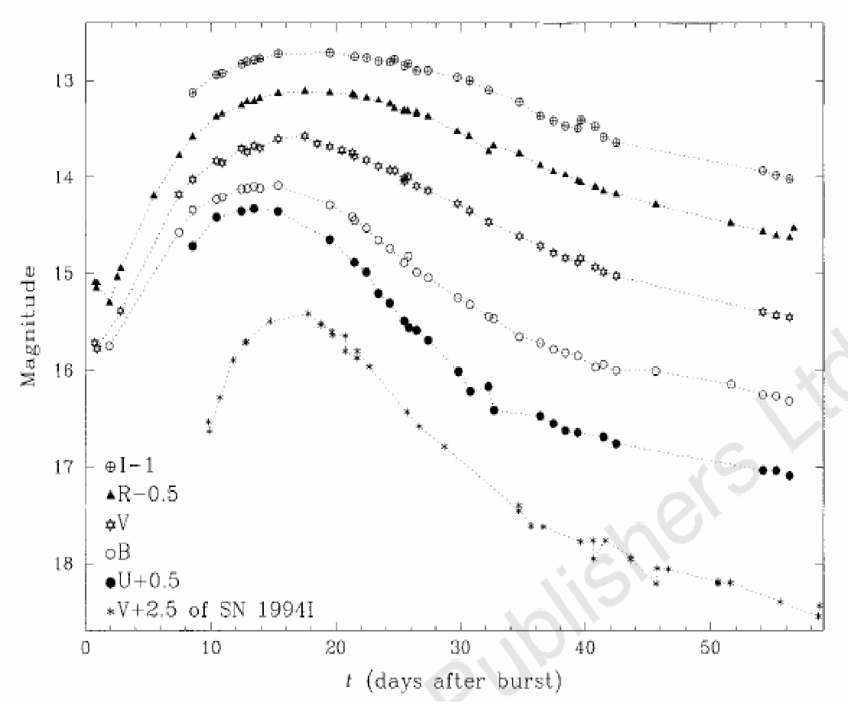


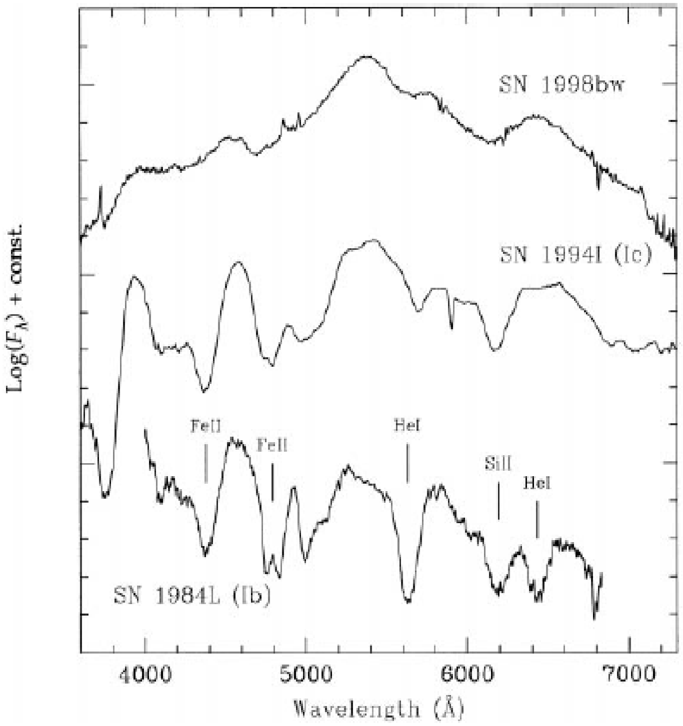
WFC error box (8') for GRB 980425 and two NFI x-ray sources. The IPN error arc is also shown.

d=40 Mpc
10^48 erg in gamma-rays

Hypernova prototype – SN1998bw: an unusual SN

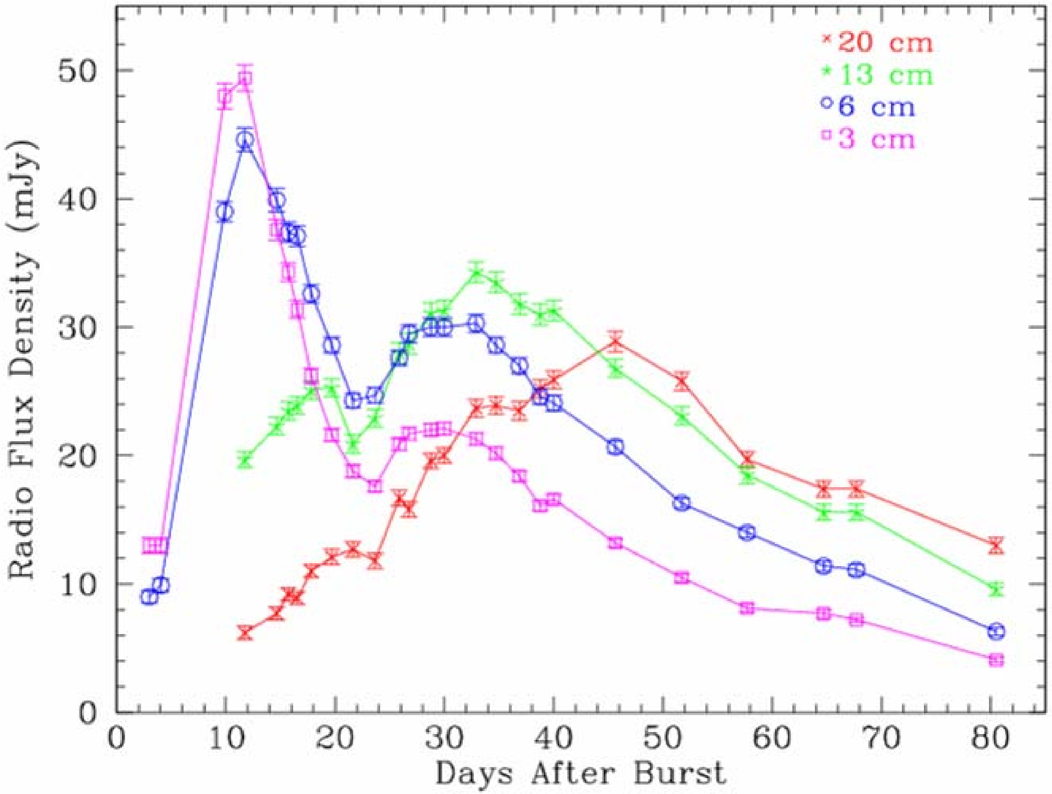
In the error box of GRB980425





1) Type Ic SN (Wolf-Rayet star progenitor)
2) High peak luminosity, broad emission lines
3) modelling requires large explosion energy E=3-5e52erg (Iwamoto et al. 1998; Woosley et al. 1999)

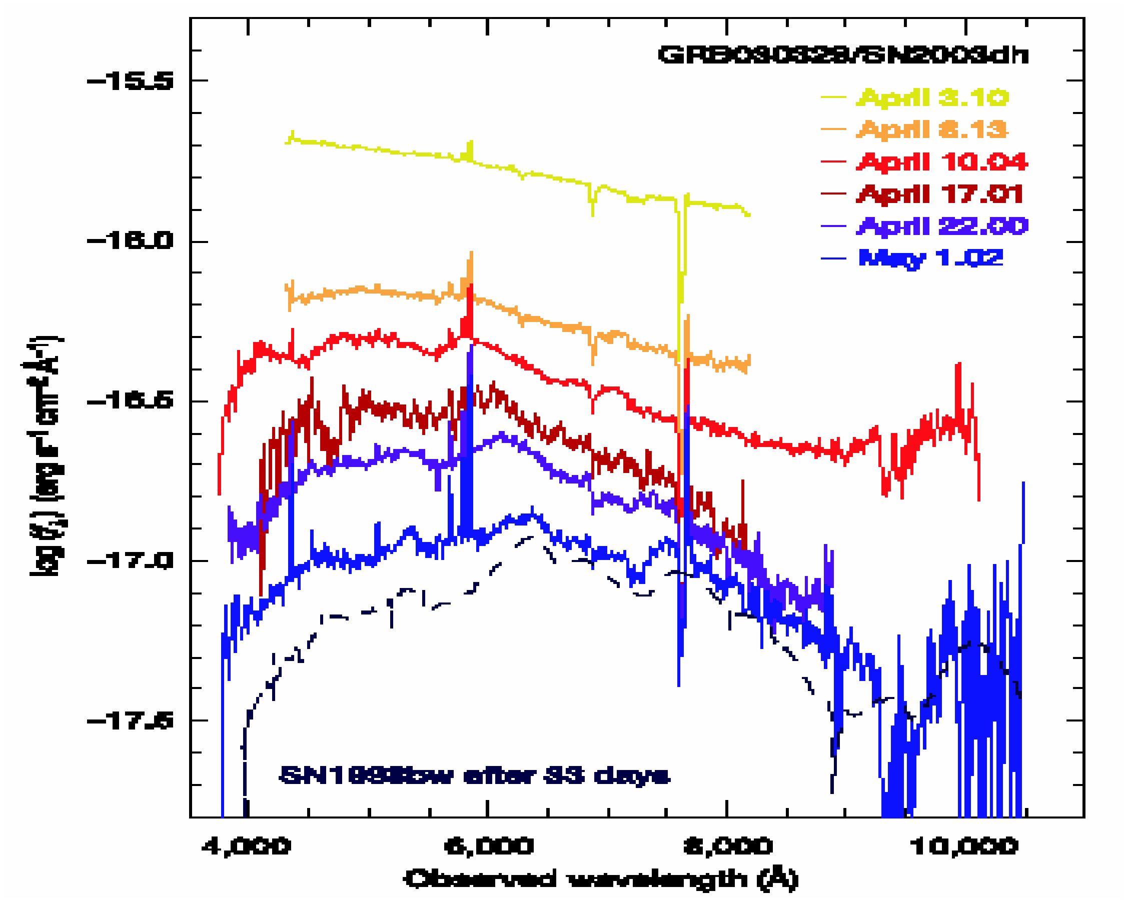
Radio emission--Mildly Relativistic Ejecta



Bright radio emission for first 3 weeks requires \Gamma ~2

Kulkarni et al. 1998

A more usual GRB with supernova – GRB030329



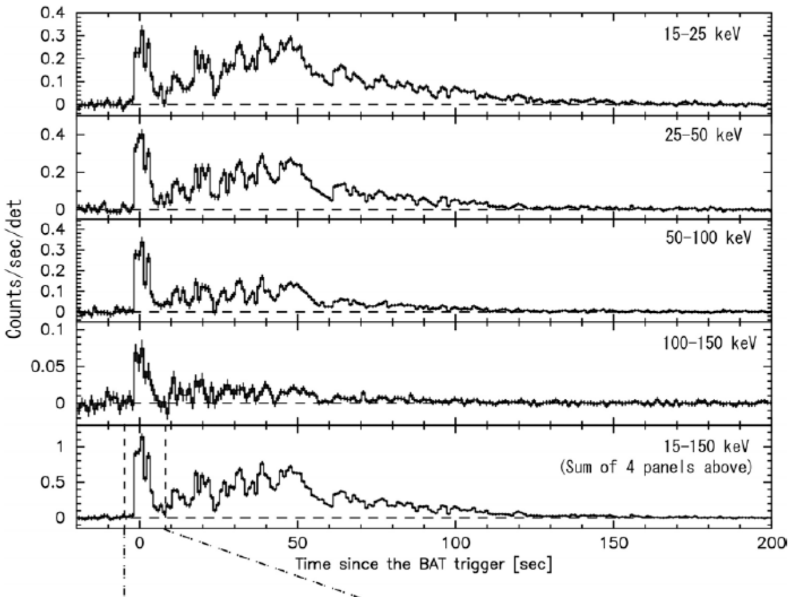
GRB 030329

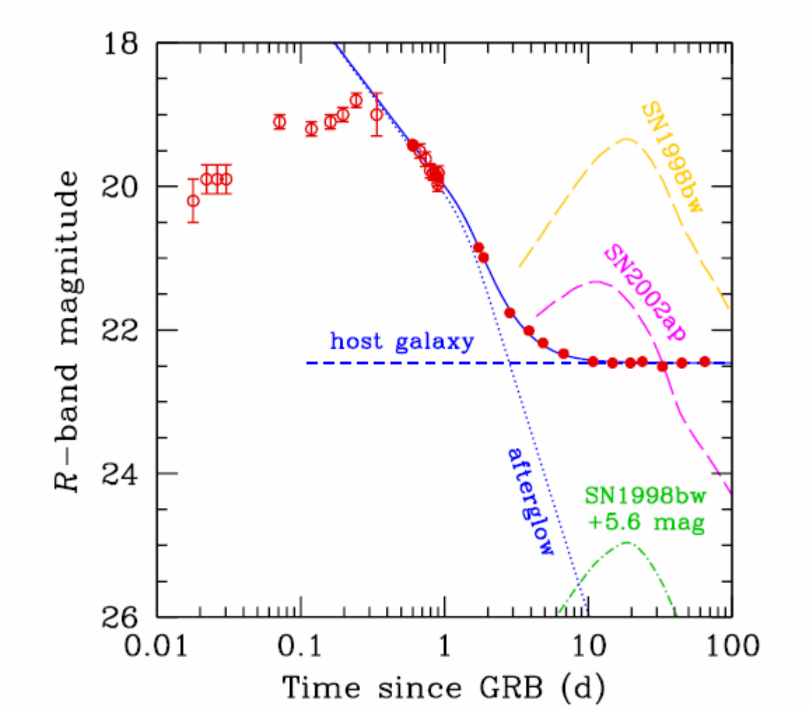
z=0.16

E_iso~10^51erg

Exceptions exist – GRB060614

- Long duration GRB, while no accompanying SN

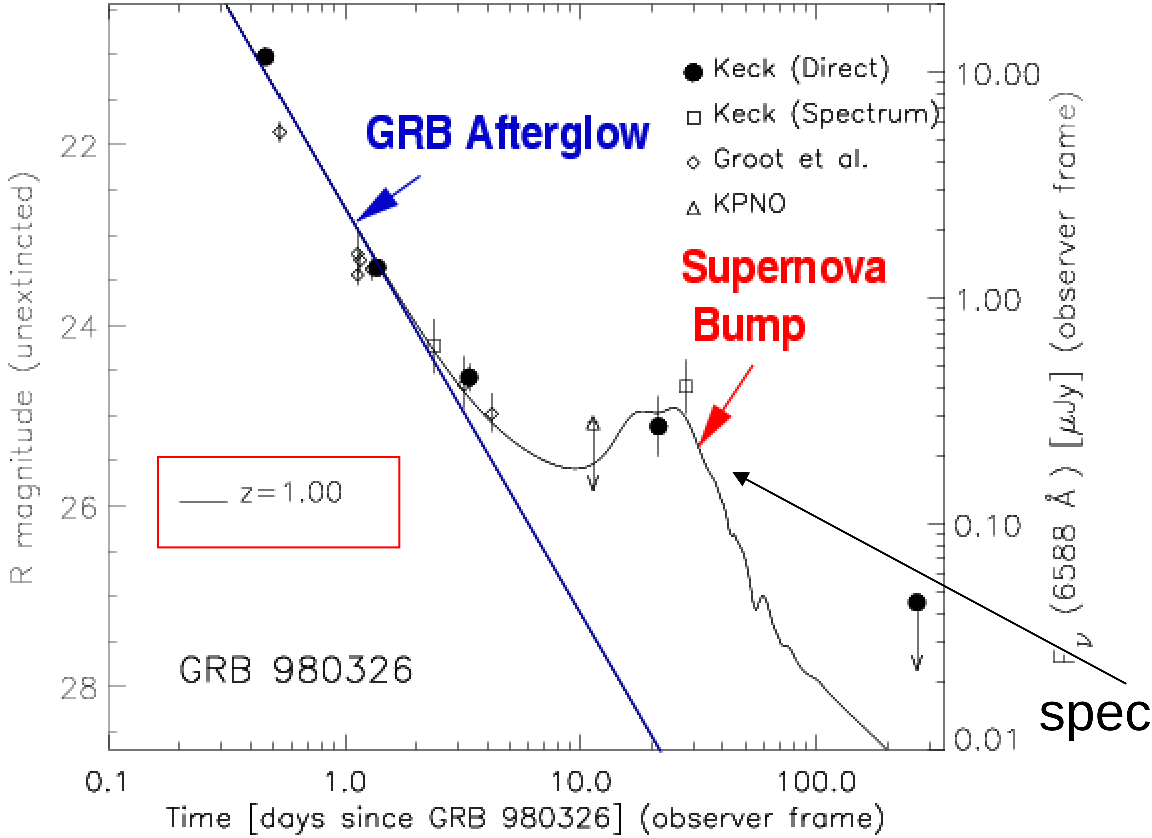




Models: Zhang et al. 2007; Lu, Huang & Zhang 2008

Observational evidence for GRB-SN connection: III

Late-time supernova bumps



spectrum redder

2. Theoretical aspects of GRB-SN connection

- Collapsar model---wildly accepted picture

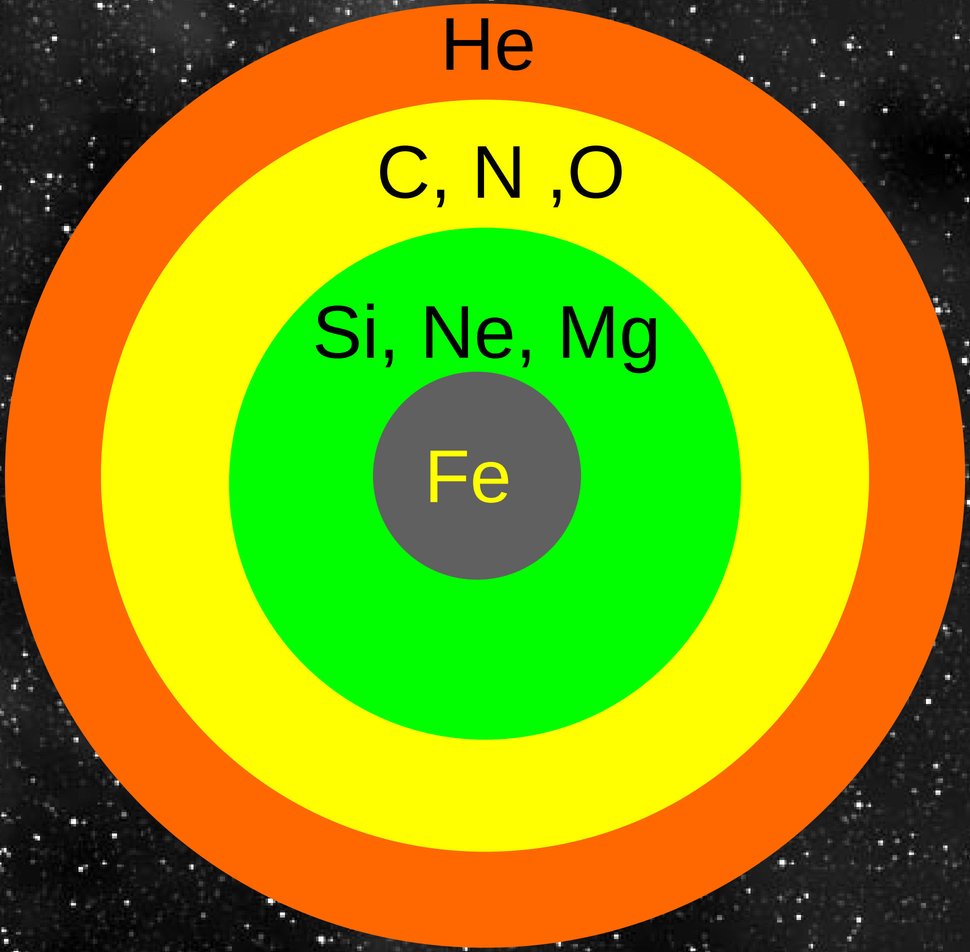
Woosley et al. 1993

Macfadyen & Woosley 1999

Zhang, Woosely, Macfadyen 2003

…

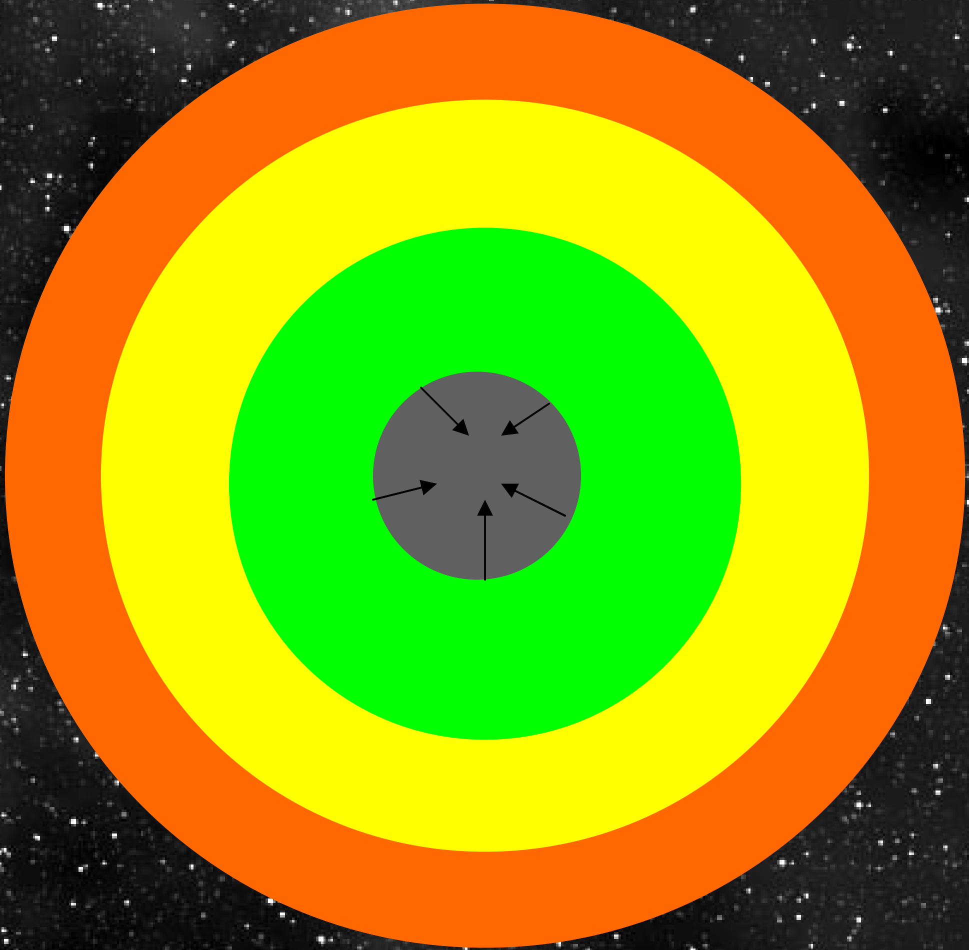
Collapsar: A Cartoon



A few Myr later, it has blown off most of its H envelope

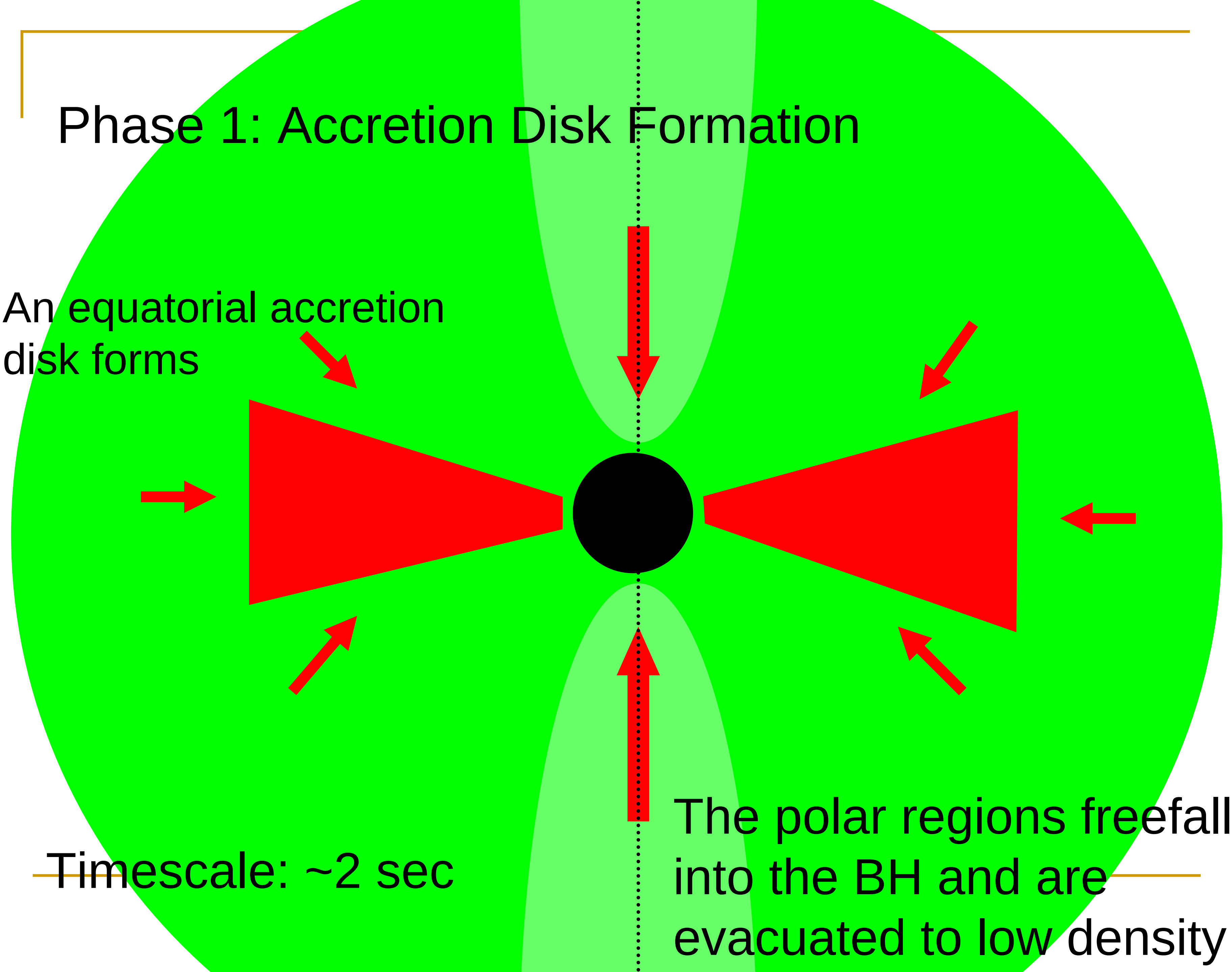
$M_{He} \sim 14M_{sun}$

Collapsar: A Cartoon



core collapse begins. $M_{Fe} \sim 2\ M_{sun}$

Phase 1: Accretion Disk Formation

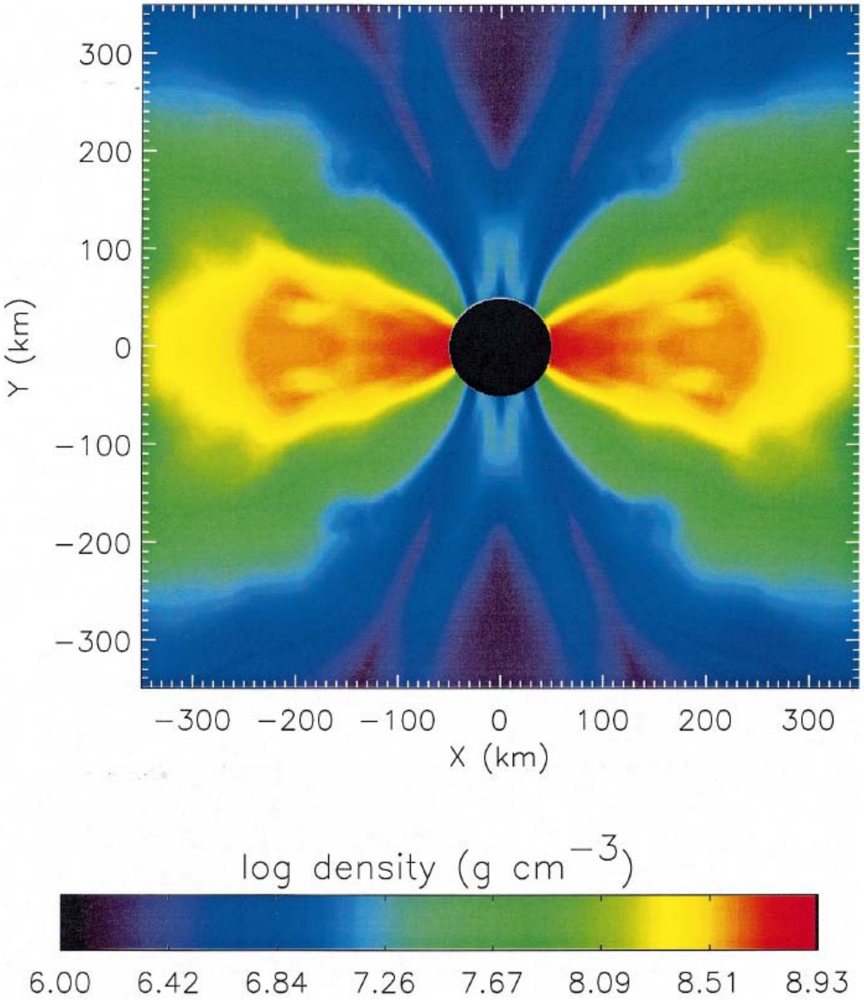


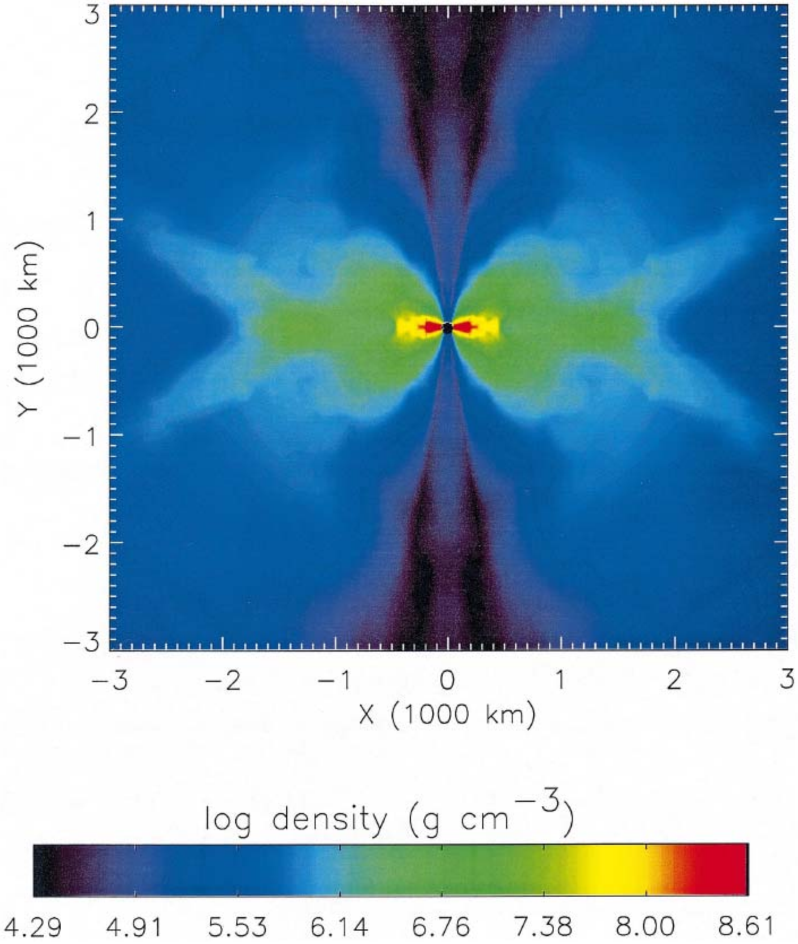
An equatorial accretion disk forms

The polar regions freefall into the BH and are evacuated to low density

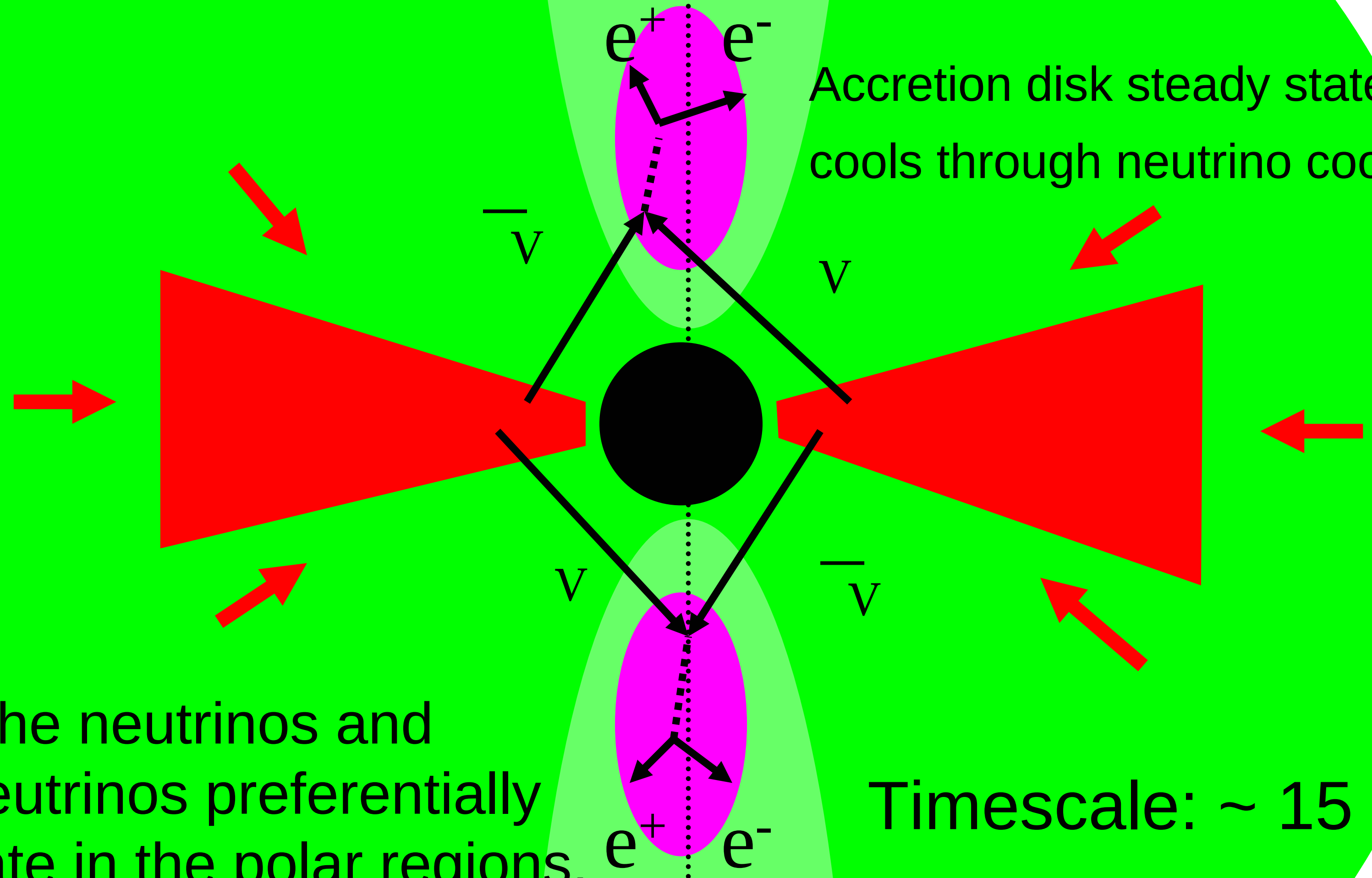
Timescale: ~2 sec

Simulation by Macfadyen & Woosley 1999





Phase 2: Accretion

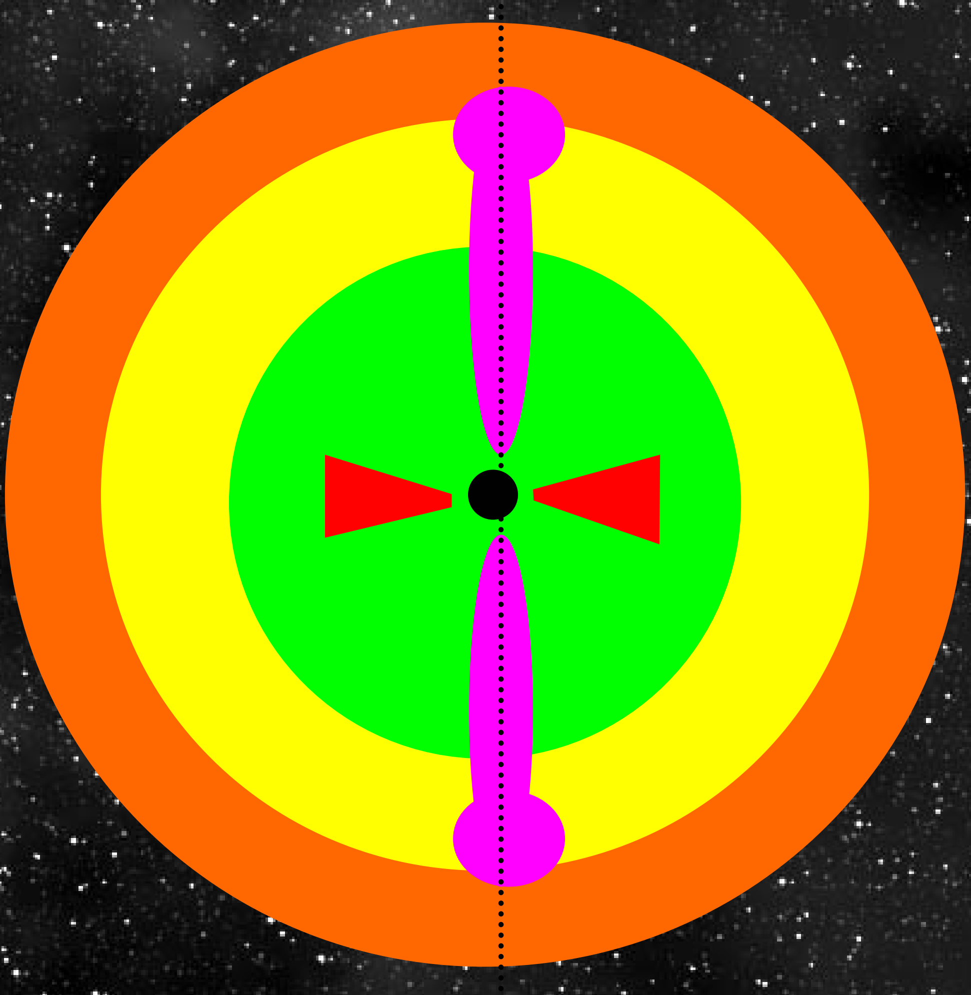


Accretion disk steady state; disk cools through neutrino cooling

The neutrinos and antineutrinos preferentially annihilate in the polar regions, creating a pair plasma with outward momentum

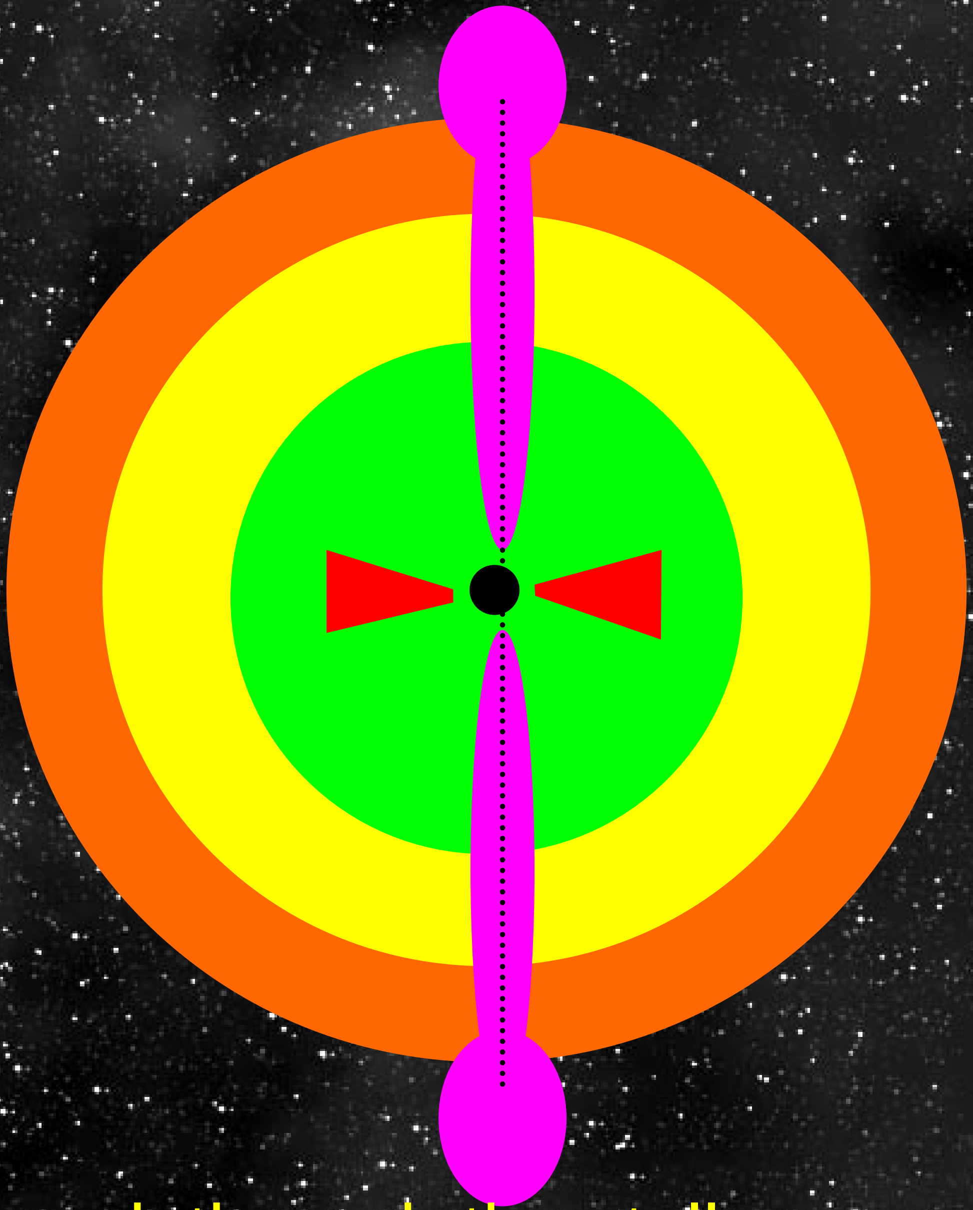
Timescale: ~ 15 s

Phase 3



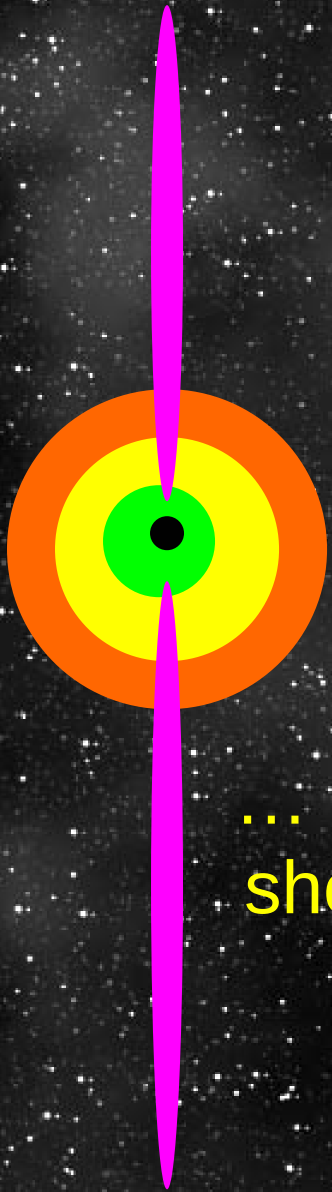
The pair-plasma (fireball) jets expand outward…

Collapsar: A Cartoon



… they break through the stellar envelope…

Collapsar: A Cartoon

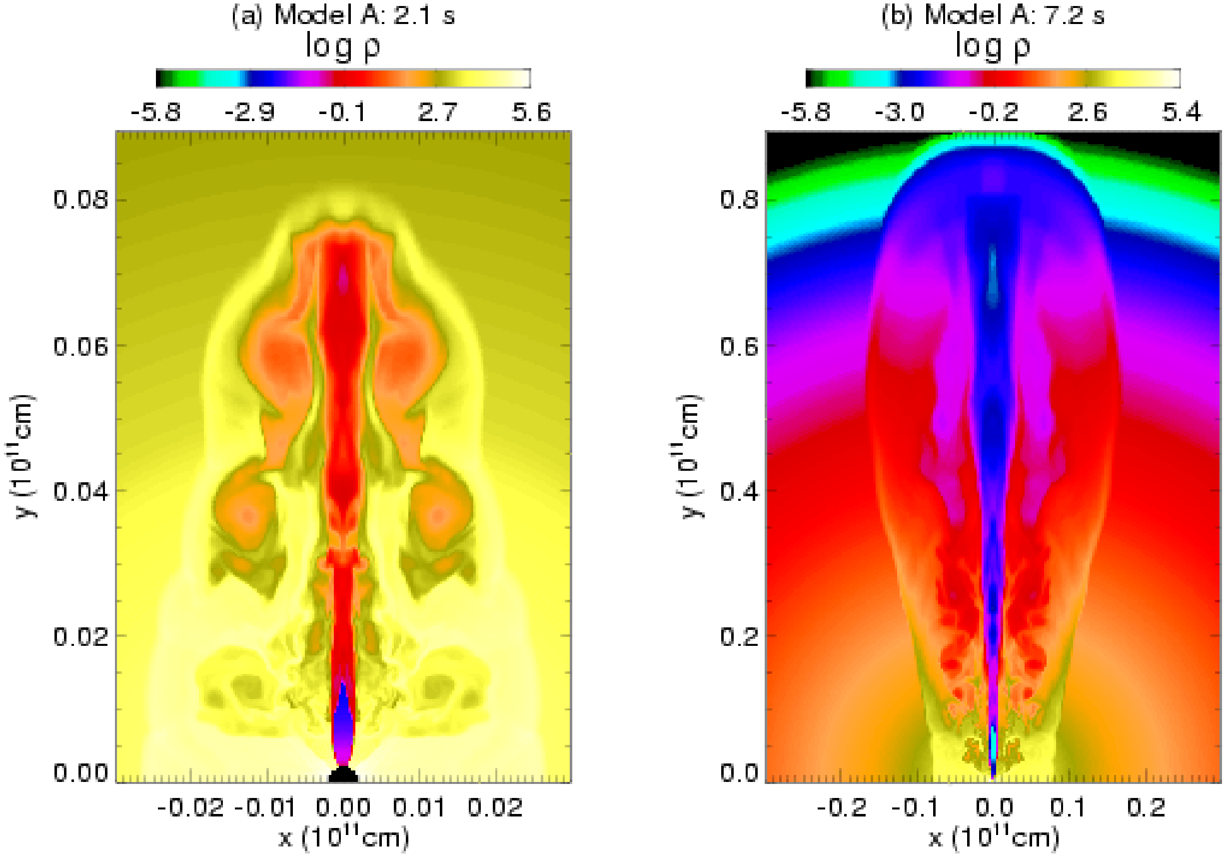


… and far away, internal shocks produce a GRB!

Simulation of Relativistic Jet Propagation Through the Star

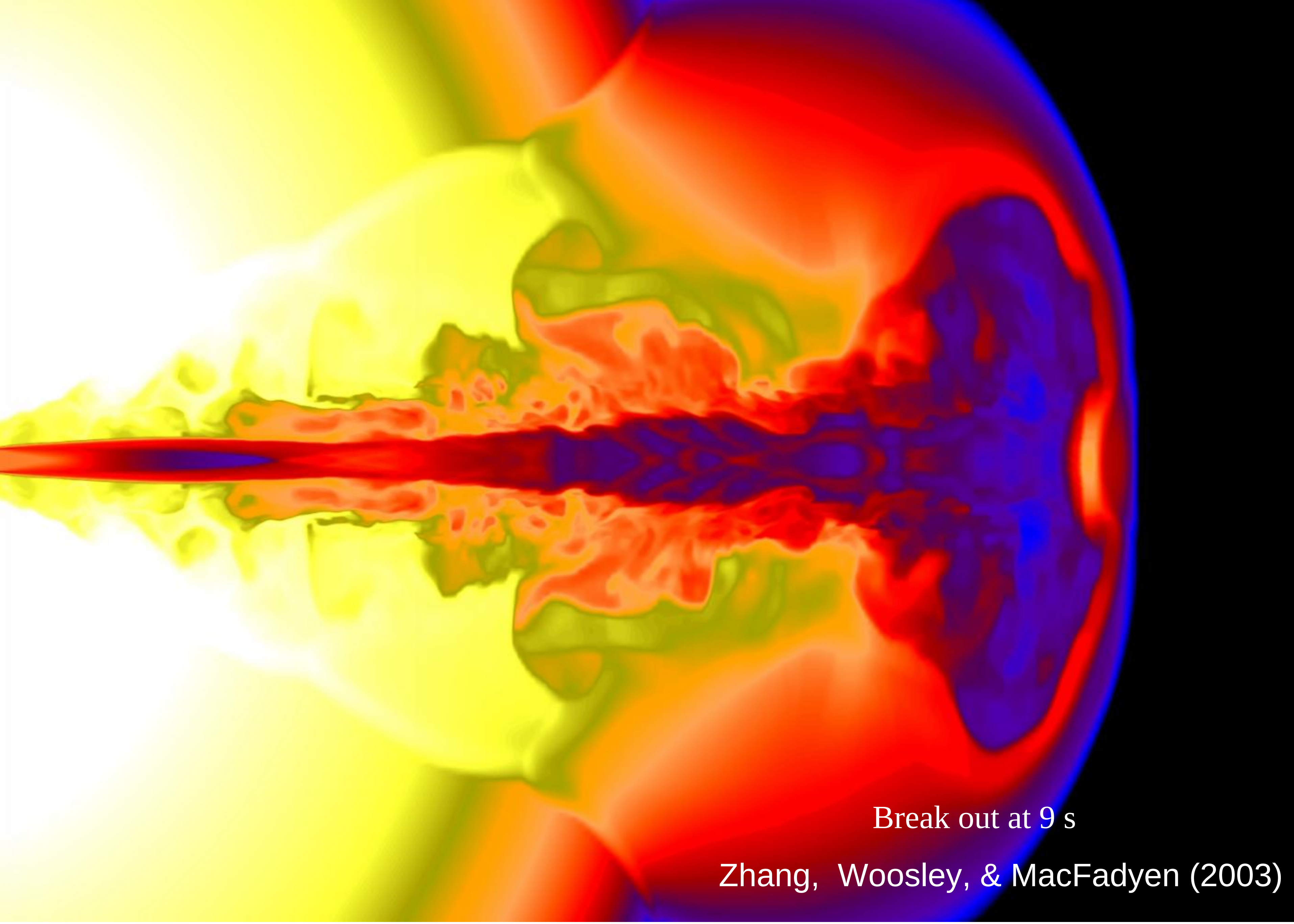
Zhang, Woosley, & MacFadyen (2002)
see also Aloy, Mueller, Ibanez, Marti, & MacFadyen (2000)

Zoom out by 10



Head moves with sub-relativistic velocity ~10^10 cm/s

Initiate a jet of specified Lorentz factor (here 50), energy flux (here 10^{51} erg/s), at a given radius (2000 km) in a given post-collapse (7 s) phase of 15 solar mass helium core evolved without mass loss assuming an initial rotation rate of 10% Keplerian.
The stars radius is 8 x 10^{10} cm. The initial opening angle of the jet is 20 degrees.

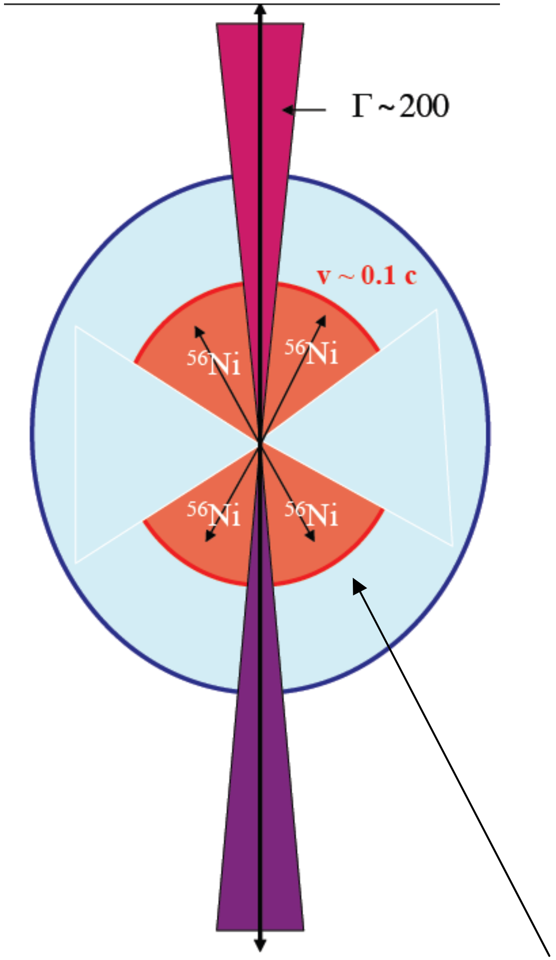


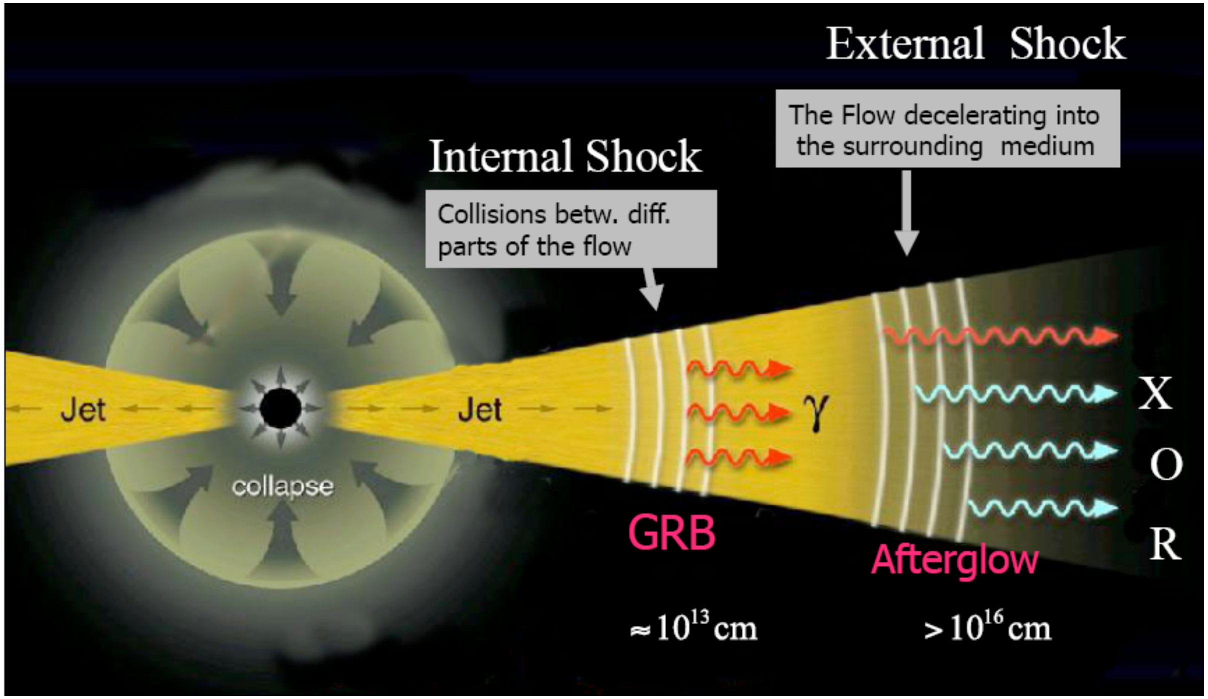
Break out at 9 s

Zhang, Woosley, & MacFadyen (2003)

Summary: Collapsar-jet-Fireball model

Meszaros & Rees 1992
Rees & Meszaros 1994





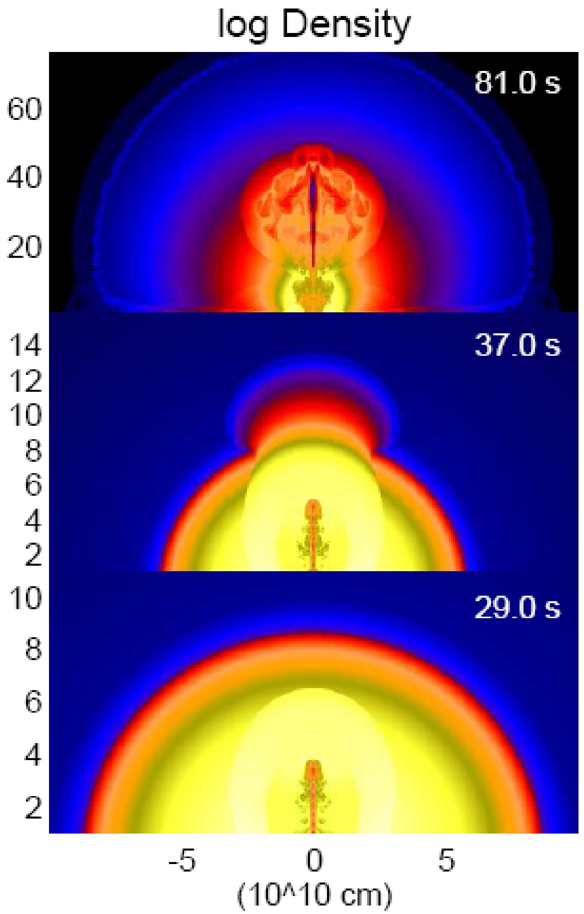
A **non-relativistic wind (v~0.1c) from the disk** produce the SN (and the Nickel)
MacFadyen & Woosley 1999

Question remains: origin of GRB980425?

- Typical GRBs have evidence of relativistic jets and supernova
- How about low-luminosity GRB like GRB980425? seems no evidence from observations
- Off-axis jet scenario is ruled out by long-term radio observation (Soderberg et al. 2006)
- Also, it is hard for low-luminosity jet to breakout of the star in a short time ~10 s

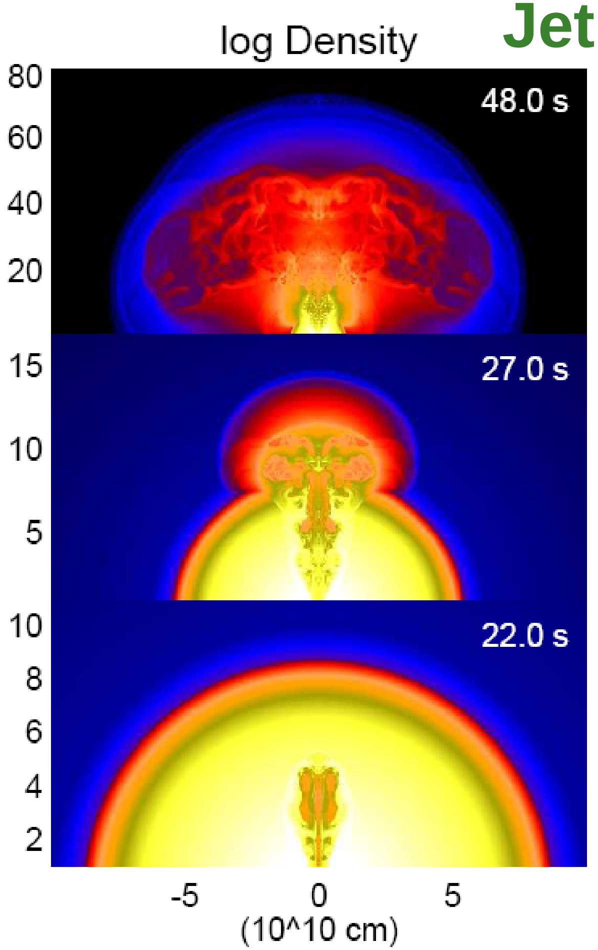
Low-luminosity GRB jet breakout

L~10^48 erg/s

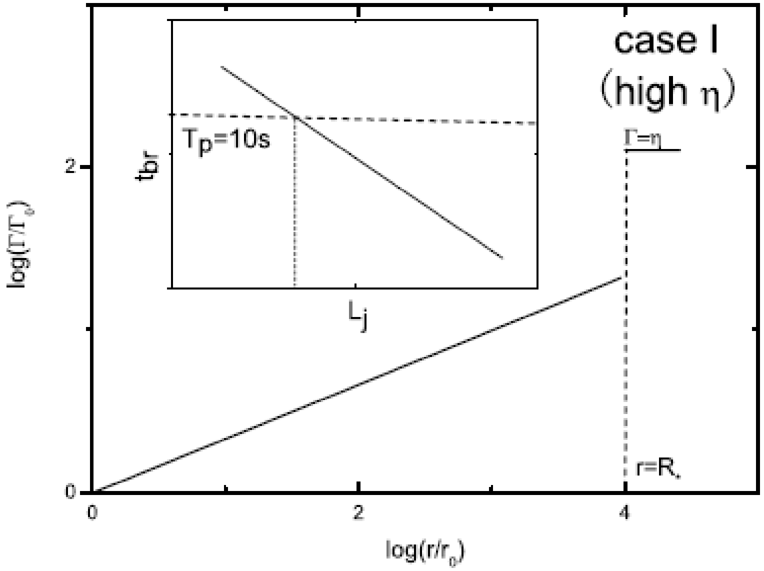


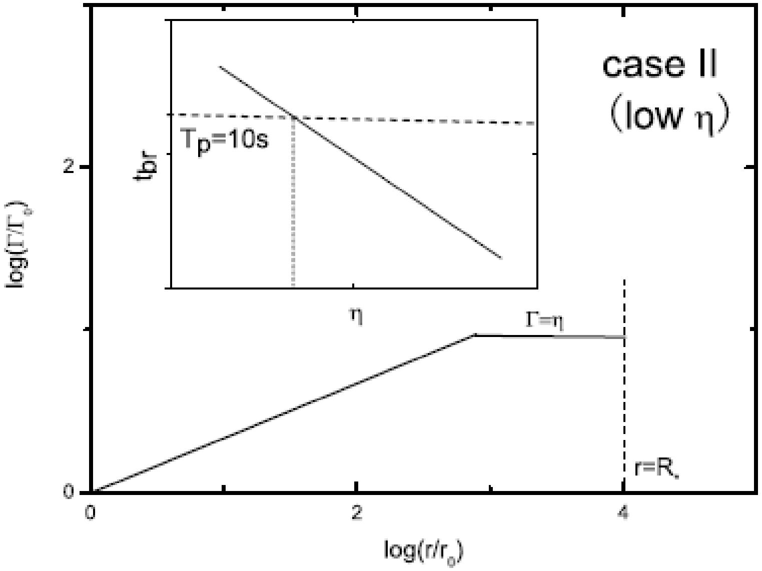
If engine stops suddenly

Jet chocked !



Analytic calculation of jet breakout time from Helium star





$$v_h = \left(\frac{L_j}{2\pi\theta_j^2 r^2 c\rho}\right)^{1/2} = 7\times10^9 r_{11}^{1/2} L_{j,49}^{1/2} \theta_{j,-2}^{-1}\ \mathrm{cm\ s^{-1}}$$

$$t = \int \frac{dr}{v_h} = \frac{\alpha r}{v_h} = 14\alpha r_{11}^{1/2} L_{j,49}^{-1/2} \theta_{j,-2}\ \mathrm{s}.$$

$$t_{\rm br} = \alpha^{8/7} r^{9/7} \left(\frac{4\pi^3\rho^3 c^2}{L_j^3}\right)^{1/7} \left(\frac{r_0\theta_0}{\Gamma_0}\right)^{4/7} = 2\alpha^{8/7} L_{j,49}^{-3/7} r_{0,7}^{4/7}\ \mathrm{s},$$

$$t_{\rm br} = \alpha^{4/3} r^{5/3} \left(\frac{L_j}{\pi\rho}\right)^{-1/3} \eta^{-4/3} = 4\alpha^{4/3} r_{11}^{2/3} L_{j,49}^{-1/3} \eta_1^{-4/3}\ \mathrm{s}.$$

Wang & Meszaros 2007

Question remains: origin of GRB980425?

- Typical GRBs have evidence of relativistic jets and supernova
- How about low-luminosity GRB like GRB980425? seems no evidence from observations
- Off-axis jet scenario is ruled out by long-term radio observation (Soderberg et al. 2006)
- Also, it is hard for low-luminosity jet to breakout of the star in a short time ~10 s
- Maybe, we do not it need at all (e.g. Tan, Matzner & Mckee 2001 suggest hypernova explosion shock can couple 10^50 erg in Γ ~2 ejecta)

3. Low-luminosity GRBs and hypernova shock breakout

Nearby Low-luminosity GRBs connected with supernovae

- Nearby long GRBs are connected with supernovae (Spectroscopically Identified)

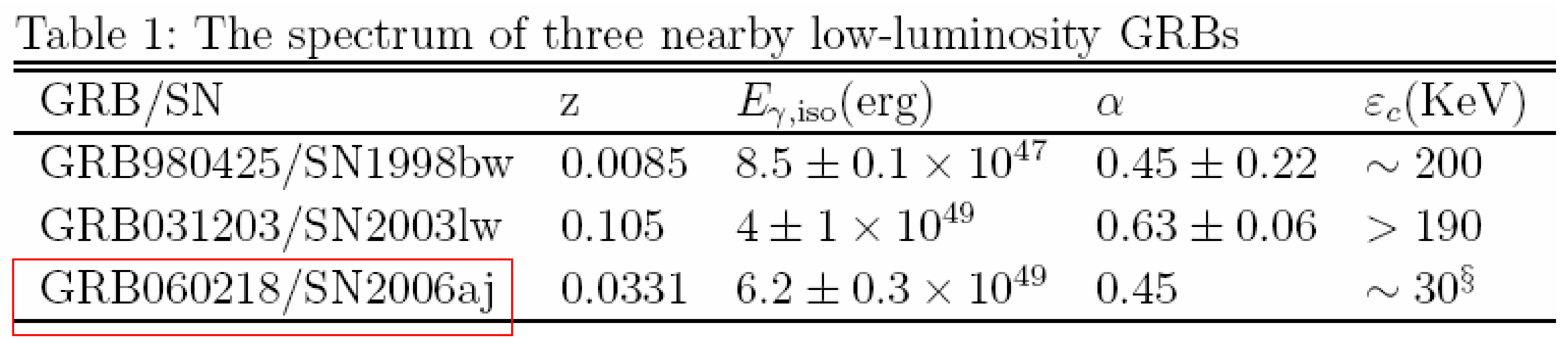


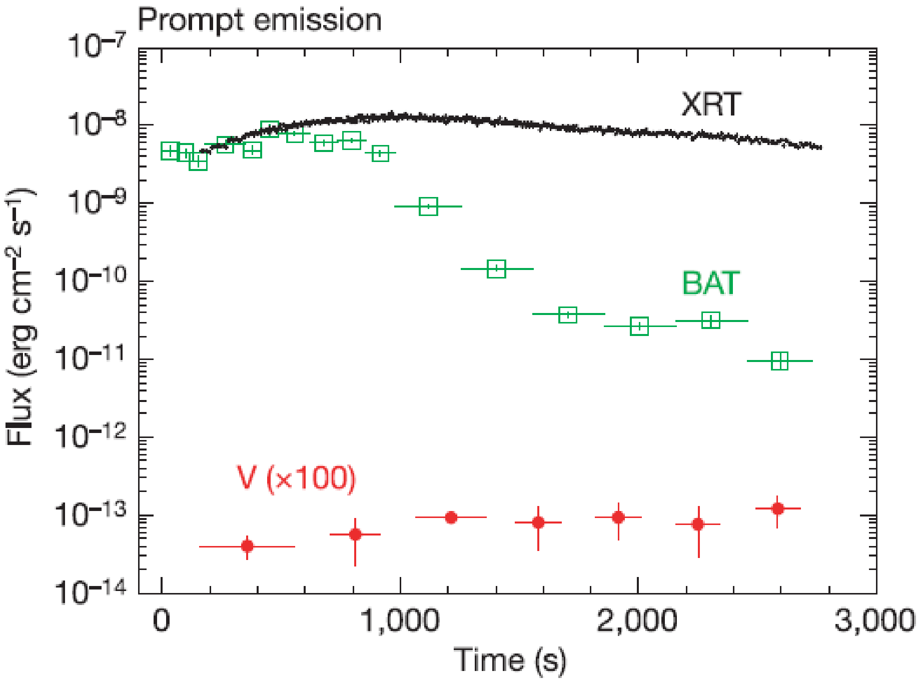
Table 1: The spectrum of three nearby low-luminosity GRBs

GRB/SN	z	$E_{\gamma,\mathrm{iso}}$(erg)	α	ε_c(KeV)
GRB980425/SN1998bw	0.0085	$8.5 \pm 0.1 \times 10^{47}$	0.45 ± 0.22	~ 200
GRB031203/SN2003lw	0.105	$4 \pm 1 \times 10^{49}$	0.63 ± 0.06	> 190
GRB060218/SN2006aj	0.0331	$6.2 \pm 0.3 \times 10^{49}$	0.45	$\sim 30^{\S}$

GRB030329-SN2003dh belongs to high luminosity

z=0.16 E_gamma=2*10^51 erg

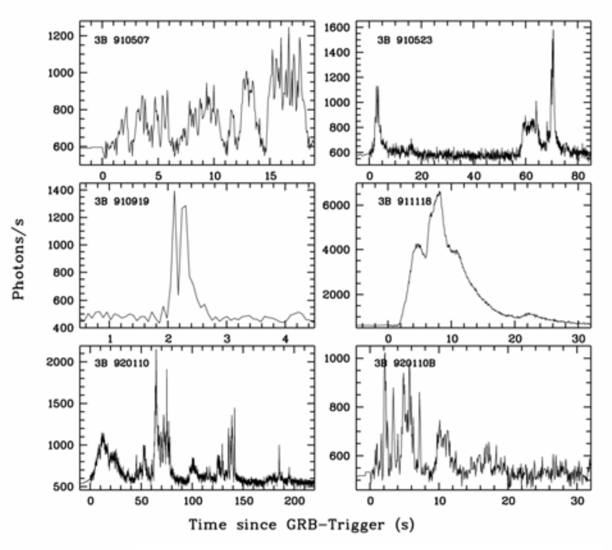
Swift discovery of GRB060218/SN2006aj



Campana et al. 2006

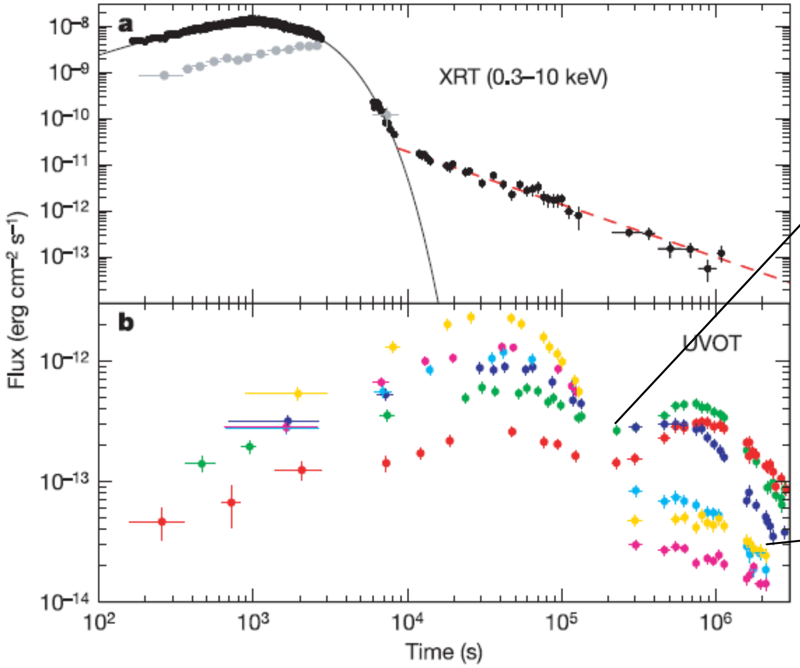
- An unusually long, smooth burst T_{90} ~ 2100 ± 100 s
- Low luminosity, low energy

  E_{iso} of ~ 6 x 10^{49} erg
- z=0.033, second nearest GRB



$$E_{\rm iso} = 10^{51} - 10^{54}\,{\rm erg}$$

Subsequent evolution—SN emerges



Campana et al. 2006

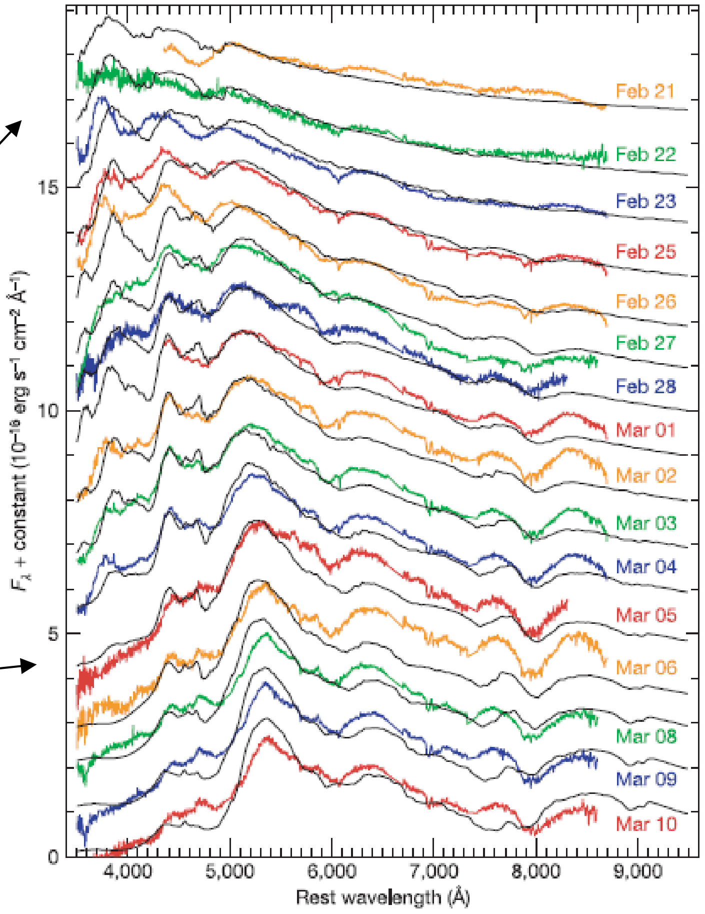
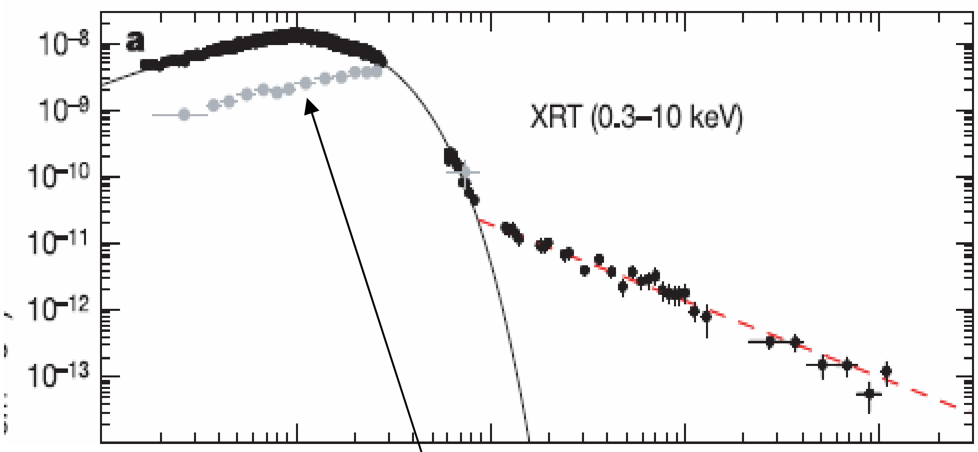
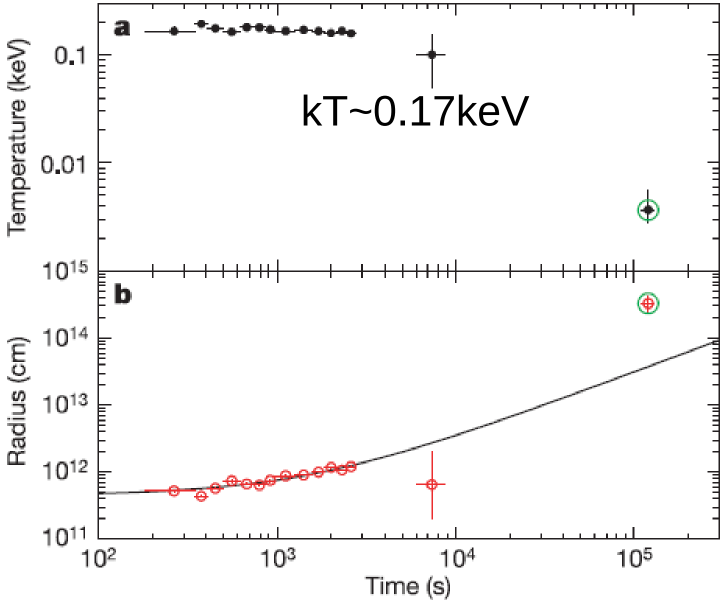


Figure 1 | Spectra of SN 2006aj and synthetic fits. The observed spectra of

Mazzali et al. 2006

A closer look at the XRT spectrum





kT~0.17keV

Figure 3 | Evolution of the soft thermal component temperature and radius. a, Evolution of the temperature of the soft thermal component. The

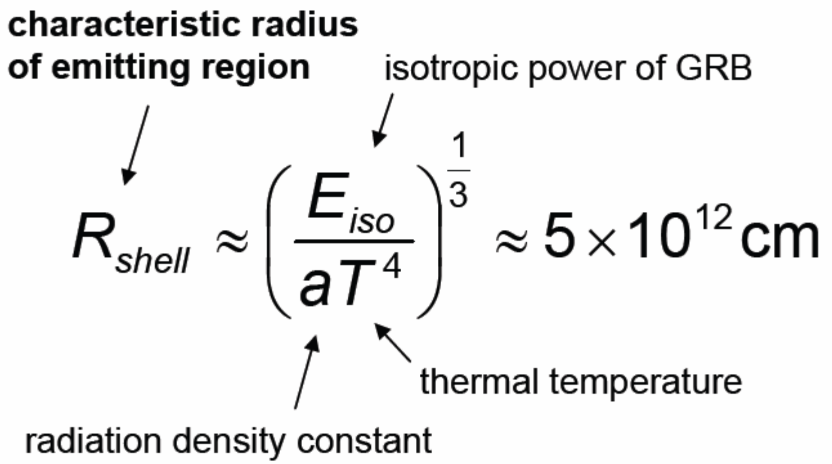
Contribution of a fitted **black-body component** to the 0.3-10KeV flux

Constitute 20% of the total XRT fluence

What's the origin of the thermal x-ray component: Shock-breakout model

- Thermal component: ~10^6 K--- an important clue
- supernova shock break-out model (Campana et al. 2006, Waxman, Meszaros & Campana 07)
- Supernova forms a radiation-dominated shock. When a SN shock approaches the surface of the star, there comes a point at which the post shock radiation can leak out, producing a burst of radiation…
- shock breaks out at the star surface (at $\tau = c/v_s$) and emits a thermal UV/X-ray flash for type II SN (predicted by, e.g. Colgate 1974; Klein & Chevalier 1974; Ensman & Burrows 1992)

Deriving the shock properties of GRB060218/SN2006aj—1) shock breakout radius



characteristic radius of emitting region

isotropic power of GRB

$$R_{shell} \approx \left(\frac{E_{iso}}{aT^4}\right)^{\frac{1}{3}} \approx 5\times10^{12}\,\mathrm{cm}$$

thermal temperature

radiation density constant

- BUT lack of Hydrogen lines implies a more compact star: larger radius explained by ***massive stellar wind***.

Campana et al. 2006

Shock front

$$\tau = c/v_s$$

2) Shock velocity: V_s~c

$$\dot{M} \sim \frac{M_{shell} V_{wind}}{R_{shell}} \sim 3 \times 10^{-4}\ \mathrm{M_{\odot} yr^{-1}}$$

$$a T_{BB}^4 \sim 3 \rho_{wind} v_{shock}^2$$

ρ_{wind} is ~10^{12} g cm^{-3} and thus $v_{shock} \approx c$

A mildly-relativistic shock with energy ~10^50 erg

What is the origin of the non-thermal component?

- Usual model: internal shock from relativistic jet collision-- rapid variability
- However, GRB060218 is unusual in

Energy: 10^49 erg, sub-energetic

Duration: ~1000sec

Luminosity: 10^46 erg/s low-luminosity GRB (GRB980425)

E_peak: low, x-ray flashes

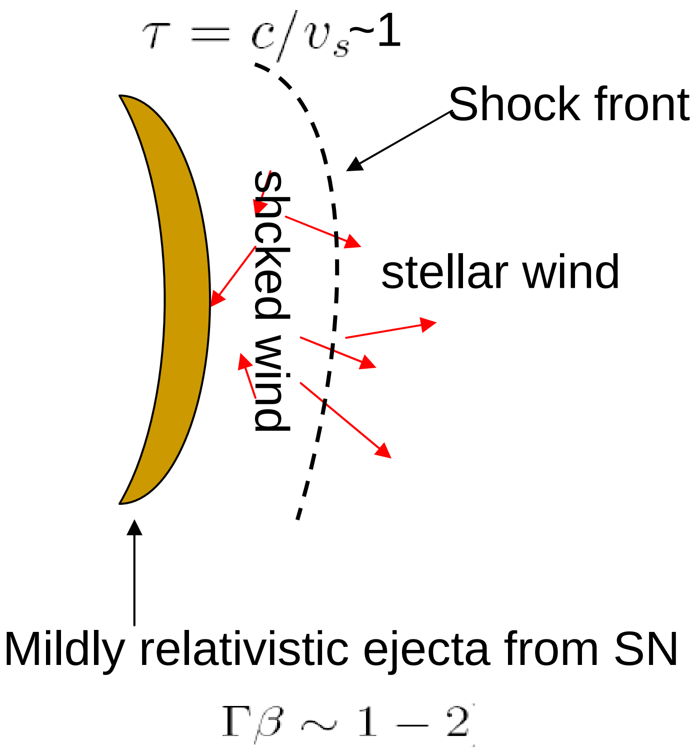
Light curve Profile: very smooth

So in many aspects, gamma-ray emission is atypical, so the mechanism could be entirely different ?

Bulk-motion Comptonization of thermal x-ray photons --- multiple scattering

Wang, Li, Waxman & Meszaros 07

- An non-negligible optical depth ahead of the shock $\tau = c/v_s$
- Some thermal photons are repeatedly scattered by the electrons to increasingly higher energy before they can escape
- "photon acceleration", giving rise to a nonthermal component
- Cold electrons, bulk-motion dominated



"Fermi acceleration"

- Photon energy amplification factor for mildly-relativistic electrons $A \sim \Gamma^2$

- Effective Compton Y parameter

  $$Y = A(1 - e^{-\tau})$$

- For $\Gamma\beta \sim 1 - 2$ and $\tau \sim 1$

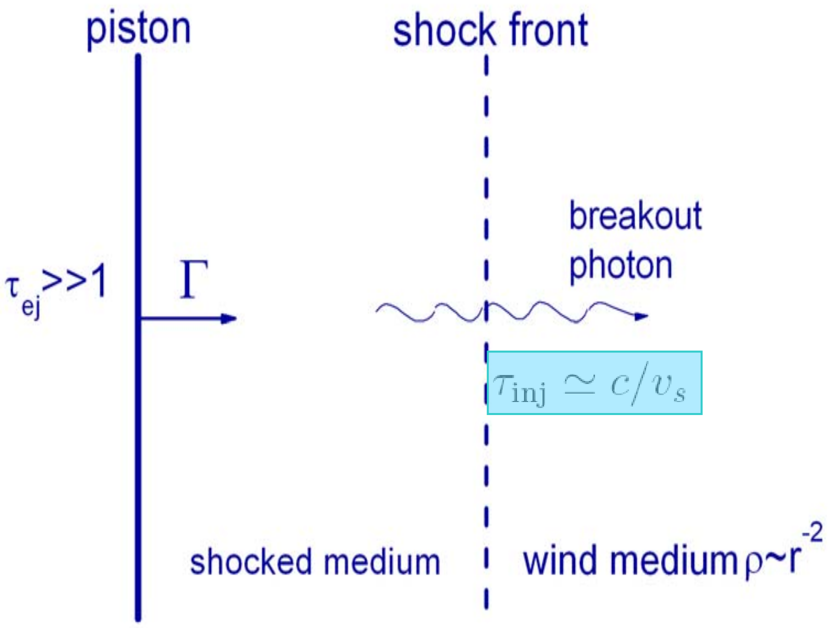
  Y>1, Compton luminosity is dominated, i.e. non-thermal component could be dominated

- All the above assume a constant τ ,

however, our case: decreasing τ due to shock moving outward

One-dimension Monte-Carlo Simulation to understand the time-dependent case

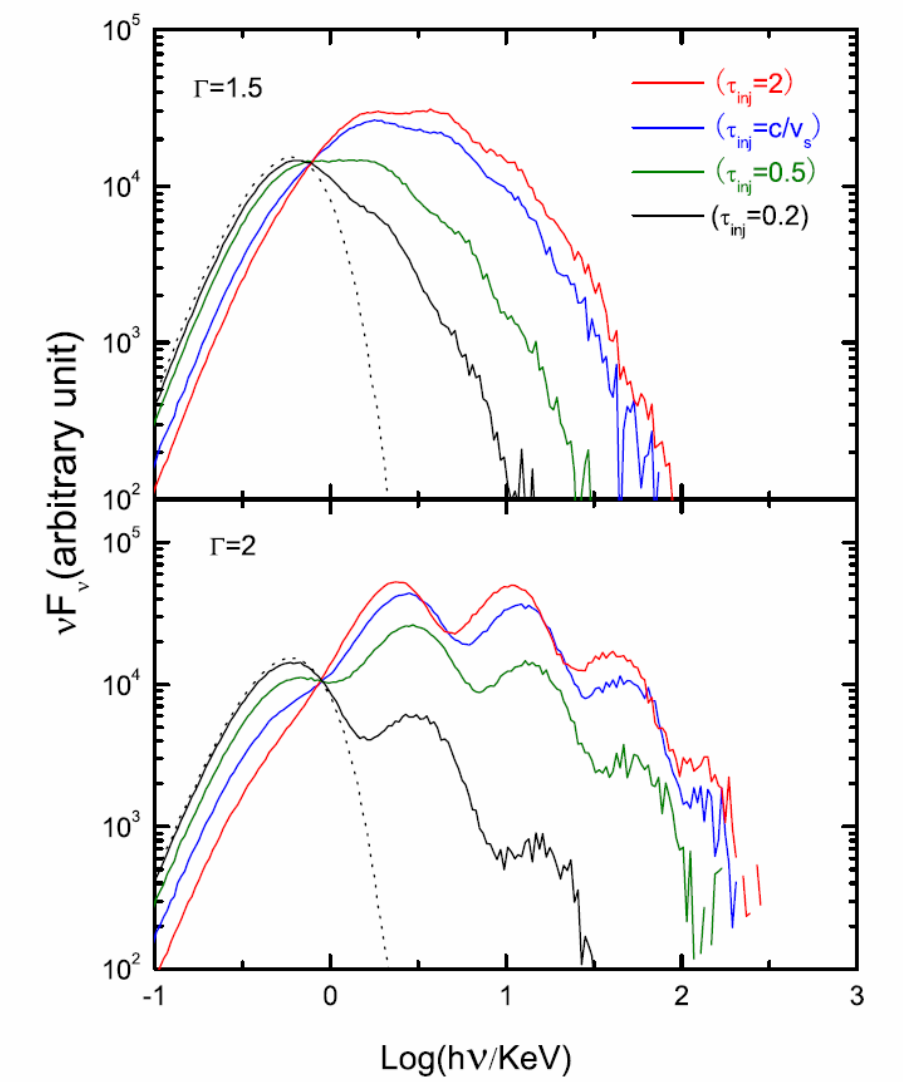
- At shock breakout radius (corresponding to $\tau_{\rm inj}$), black-body photons are injected
- Follow the scattering history until the photons come out
- Photon-electron scattering in each of three regions, with energy gain or loss
- Record the energy and arrive time of each photon: Construct the spectrum and arriving time of the escaping photons



Wang, Li, Waxman & Meszaros 07

Simulation results --- time-integrated spectrum

- 10^6 thermal “seed” photons with kT=0.15KeV (black dotted line)
- Non-thermal component is indeed dominated for mildly relativistic shock
- Larger Gamma, larger peak energy, peak energy could be around a few KeV--- X-ray Flash



wind parameters are: $\dot{M} = 10^{-4} M_{\odot} \mathrm{yr}^{-1}$ and $v_w = 10^{8} \mathrm{cms}^{-1}$

Origin of the mildly-relativist outflow

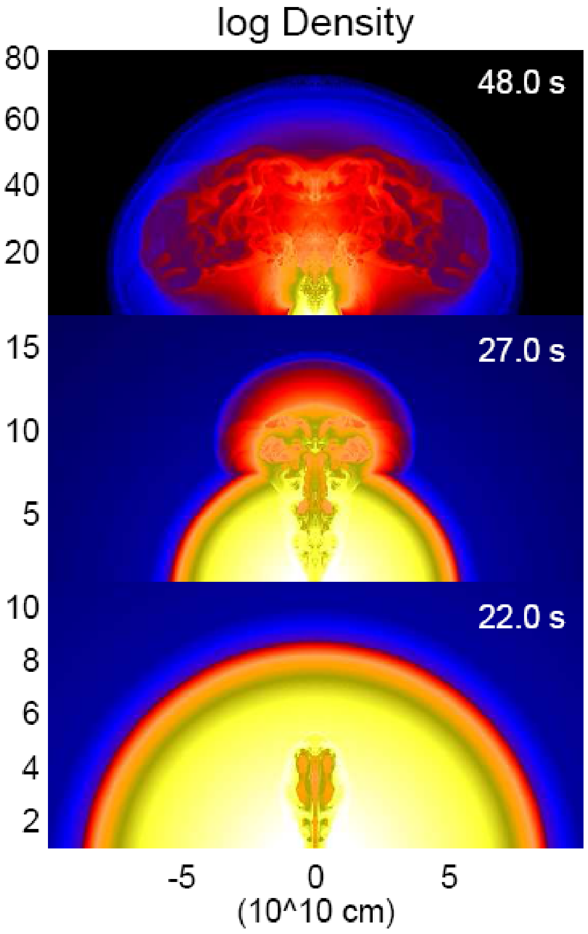
Two possibilities:

1) SN Shock acceleration
In the stellar atmosphere

$$v_{f\max} = 13{,}000\left(\frac{\kappa}{0.34\ \mathrm{cm}^2\ \mathrm{g}^{-1}}\right)^{0.13}\left(\frac{\rho_1}{\rho_*}\right)^{-0.086} \times\left(\frac{E_{\mathrm{in}}}{10^{51}\ \mathrm{ergs}}\right)^{0.57}\left(\frac{M_{\mathrm{ej}}}{10\ M_\odot}\right)^{-0.44} \times\left(\frac{R_*}{500\ R_\odot}\right)^{-0.26}\ \mathrm{km\ s}^{-1}\quad\left(n=\frac{3}{2}\right),$$

$$v_{f\max} = 33{,}000\left(\frac{\kappa}{0.34\ \mathrm{cm}^2\ \mathrm{g}^{-1}}\right)^{0.16}\left(\frac{\rho_1}{\rho_*}\right)^{-0.054} \times\left(\frac{E_{\mathrm{in}}}{10^{51}\ \mathrm{ergs}}\right)^{0.58}\left(\frac{M_{\mathrm{ej}}}{10\ M_\odot}\right)^{-0.42} \times\left(\frac{R_*}{50\ R_\odot}\right)^{-0.32}\ \mathrm{km\ s}^{-1}\quad(n=3)\ .$$

2) Chocked Jet



Matzner & Mckee 1999
Tan, Matzner & Mckee 2001

Low Γ and high Γ jets

- Cosmological GRBs have evidence of relativistic jets (e.g. jet breaks, compactness problem of gamma-ray emission, internal shocks)
- Some people: low-luminosity GRBs are low-luminosity jets with internal shocks
- We suggest: nearby low-luminosity SN-GRBs only have evidence of mildly-relativistic ejecta; gamma/X rays may come from the shock breakout of this semi-relativistic hypernova

4. X-ray outburst associated with ordinary SN 2008D- Shock breakout emission detected?

- Hypernova shock breakout

low-luminosity GRB or X-ray flashes

- Normal core-collapse SN shock breakout

1) Type II --- thermal UV-optical outburst (e.g. Klein & Chevalier 1978; Ensman & Burrows 1992)

2) Type Ib/c --- thermal UV-soft x-ray outburst?

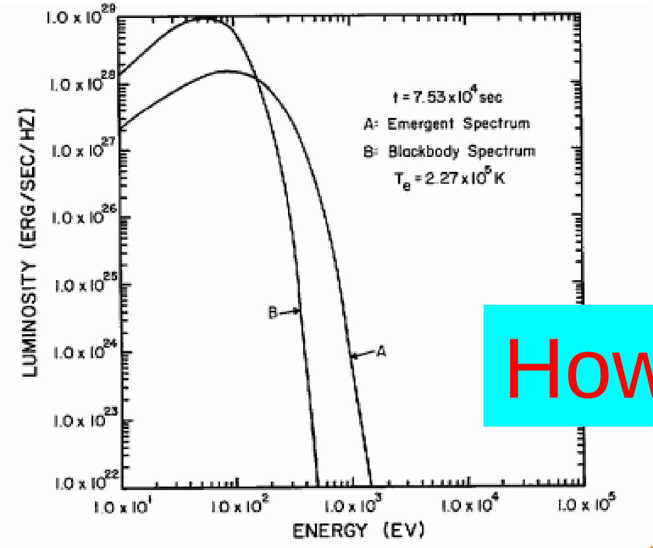
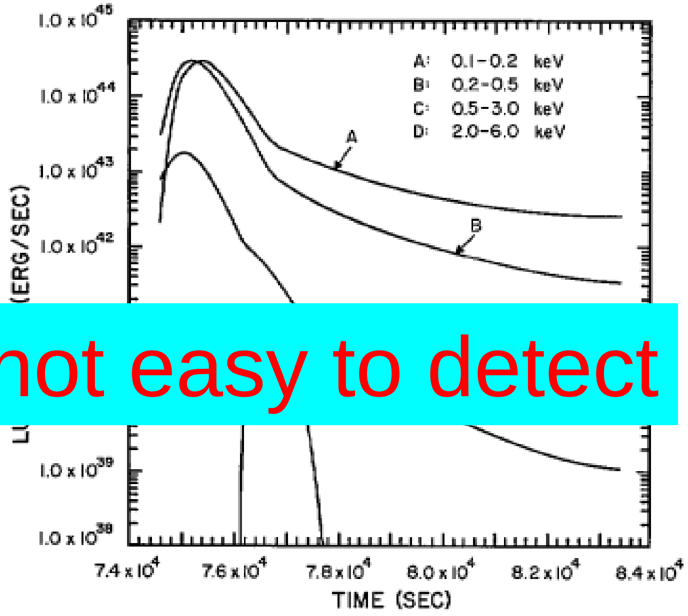


Fig. 1.—The emergent spectrum (A) was computed by a detailed solution to the non–LTE equation of radiative transfer. The blackbody spectrum temperature is taken at $\tau_R = 0.67$.



However, not easy to detect

Klein & Chevalier 1978

Predicted shock breakout emission-more recent calculation (Matzner & Mckee 1999)

$$T_{\rm se} = 5.55 \times 10^{5} \left(\frac{\kappa}{0.34\ {\rm cm}^{2}\ {\rm g}^{-1}}\right)^{-0.10} \left(\frac{\rho_1}{\rho_*}\right)^{0.070} \times \left(\frac{E_{\rm in}}{10^{51}\ {\rm ergs}}\right)^{0.20} \left(\frac{M_{\rm ej}}{10\ M_\odot}\right)^{-0.052} \times \left(\frac{R_*}{500\ R_\odot}\right)^{-0.54} {\rm K} \quad \left(n = \frac{3}{2}\right),$$

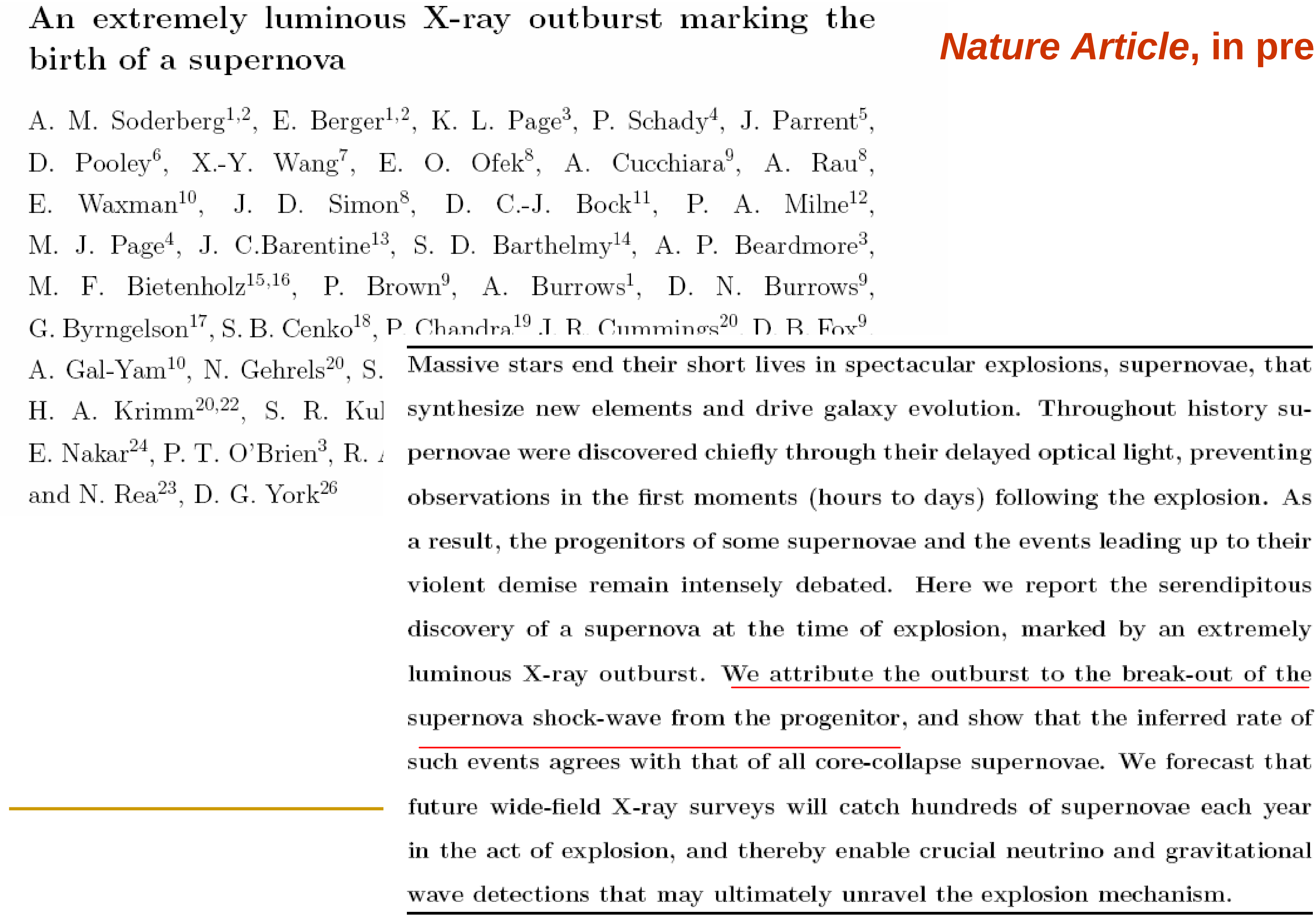
$$T_{\rm se} = 1.31 \times 10^{6} \left(\frac{\kappa}{0.34\ {\rm cm}^{2}\ {\rm g}^{-1}}\right)^{-0.14} \left(\frac{\rho_1}{\rho_*}\right)^{0.046} \times \left(\frac{E_{\rm in}}{10^{51}\ {\rm ergs}}\right)^{0.18} \left(\frac{M_{\rm ej}}{10\ M_\odot}\right)^{-0.068} \times \left(\frac{R_*}{50\ R_\odot}\right)^{-0.48} {\rm K} \quad (n = 3)\ .$$

$$E_{\rm se} = 1.7 \times 10^{48} \left(\frac{\kappa}{0.34\ {\rm cm}^{2}\ {\rm g}^{-1}}\right)^{-0.87} \left(\frac{\rho_1}{\rho_*}\right)^{-0.086} \times \left(\frac{E_{\rm in}}{10^{51}\ {\rm ergs}}\right)^{0.56} \left(\frac{M_{\rm ej}}{10\ M_\odot}\right)^{-0.44} \times \left(\frac{R_*}{500\ R_\odot}\right)^{1.74} {\rm ergs} \quad \left(n = \frac{3}{2}\right),$$

$$E_{\rm se} = 7.6 \times 10^{46} \left(\frac{\kappa}{0.34\ {\rm cm}^{2}\ {\rm g}^{-1}}\right)^{-0.84} \left(\frac{\rho_1}{\rho_*}\right)^{-0.054} \times \left(\frac{E_{\rm in}}{10^{51}\ {\rm ergs}}\right)^{0.58} \left(\frac{M_{\rm ej}}{10\ M_\odot}\right)^{-0.42} \times \left(\frac{R_*}{50\ R_\odot}\right)^{1.68} {\rm ergs} \quad (n = 3)\ .$$

X-ray outburst from SN2008D

***Nature Article*, in press**



An extremely luminous X-ray outburst marking the birth of a supernova

A. M. Soderberg[1,2], E. Berger[1,2], K. L. Page[3], P. Schady[4], J. Parrent[5], D. Pooley[6], X.-Y. Wang[7], E. O. Ofek[8], A. Cucchiara[9], A. Rau[8], E. Waxman[10], J. D. Simon[8], D. C.-J. Bock[11], P. A. Milne[12], M. J. Page[4], J. C.Barentine[13], S. D. Barthelmy[14], A. P. Beardmore[3], M. F. Bietenholz[15,16], P. Brown[9], A. Burrows[1], D. N. Burrows[9], G. Byrngelson[17], S. B. Cenko[18], P. Chandra[19] J. R. Cummings[20] D. B. Fox[9],

A. Gal-Yam[10], N. Gehrels[20], S.

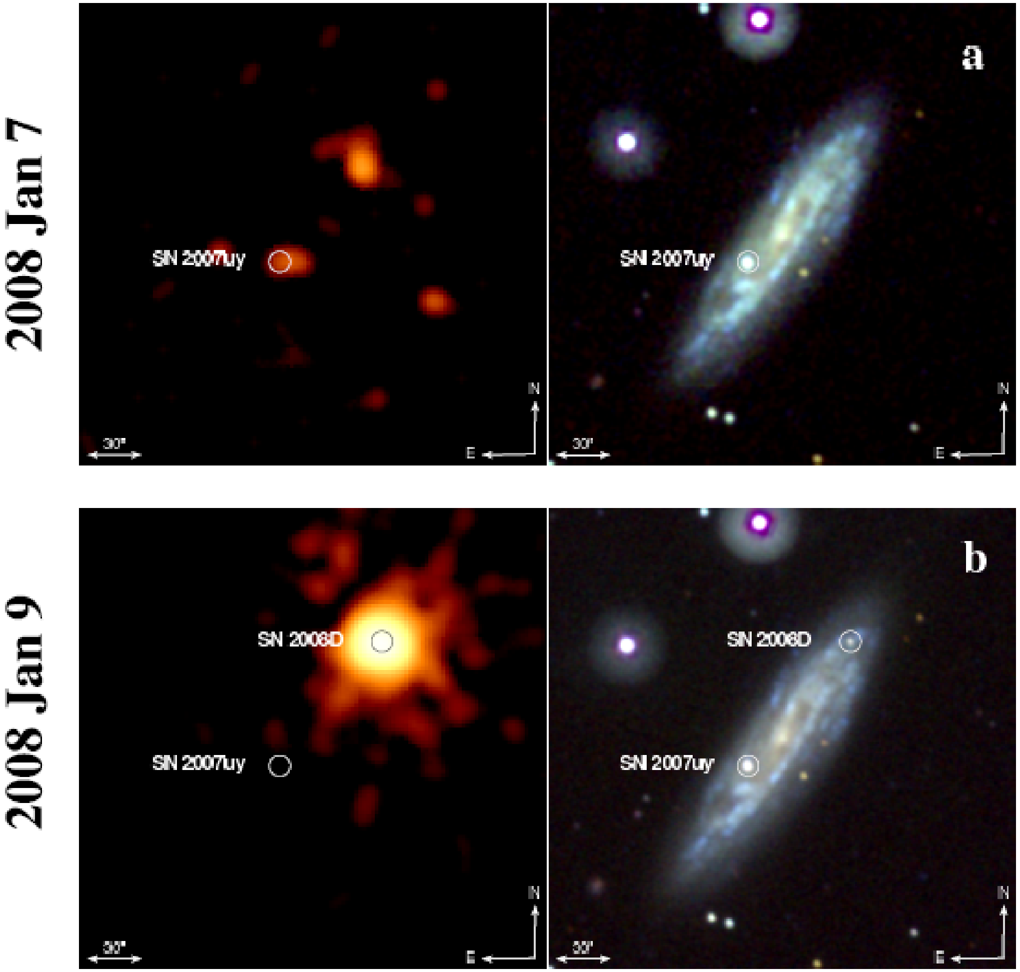
H. A. Krimm[20,22], S. R. Ku

E. Nakar[24], P. T. O'Brien[3], R.

and N. Rea[23], D. G. York[26]

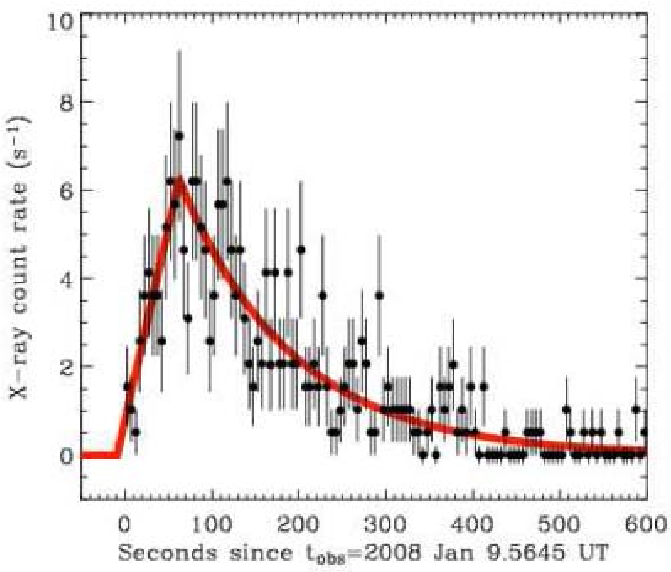
Massive stars end their short lives in spectacular explosions, supernovae, that synthesize new elements and drive galaxy evolution. Throughout history supernovae were discovered chiefly through their delayed optical light, preventing observations in the first moments (hours to days) following the explosion. As a result, the progenitors of some supernovae and the events leading up to their violent demise remain intensely debated. Here we report the serendipitous discovery of a supernova at the time of explosion, marked by an extremely luminous X-ray outburst. We attribute the outburst to the break-out of the supernova shock-wave from the progenitor, and show that the inferred rate of such events agrees with that of all core-collapse supernovae. We forecast that future wide-field X-ray surveys will catch hundreds of supernovae each year in the act of explosion, and thereby enable crucial neutrino and gravitational wave detections that may ultimately unravel the explosion mechanism.

Serendipitous discovery of SN2008D by Swift (d=27Mpc)



Not trigger!

X-ray outburst



$$E_X \approx 2 \times 10^{46} \text{ erg}$$

Comparable to shock breakout prediction

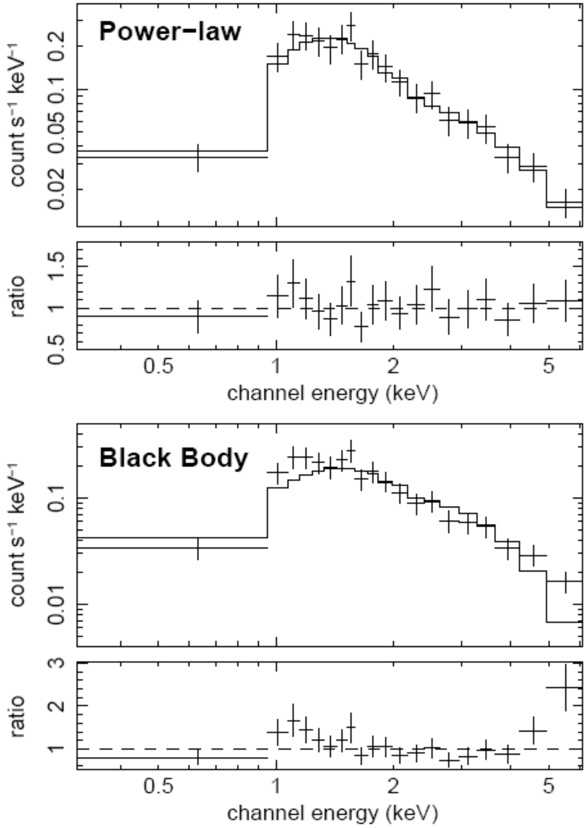
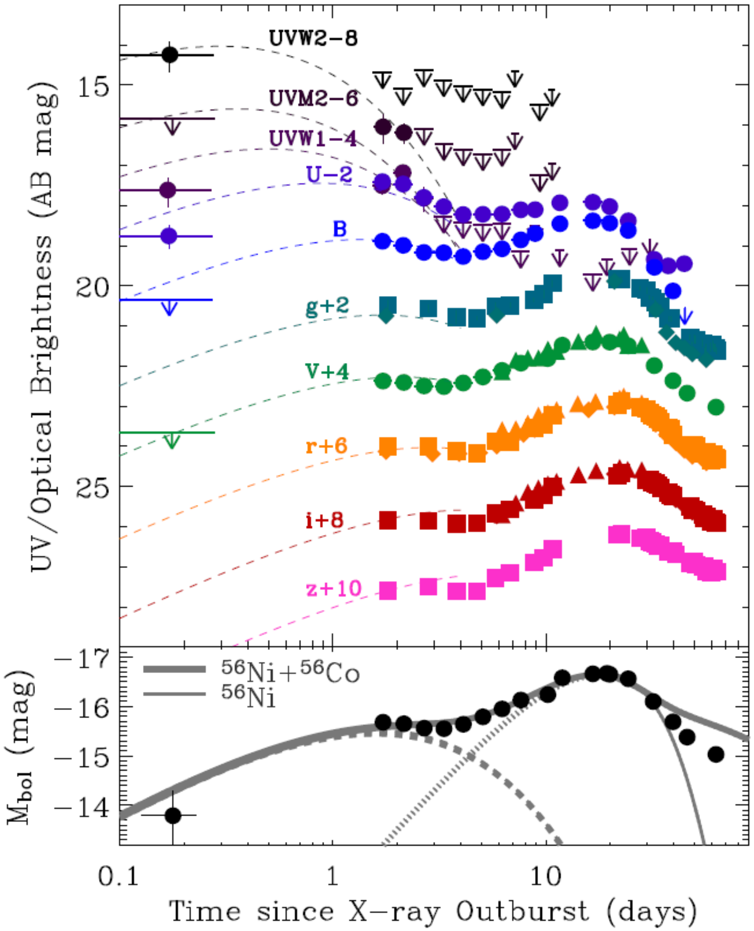
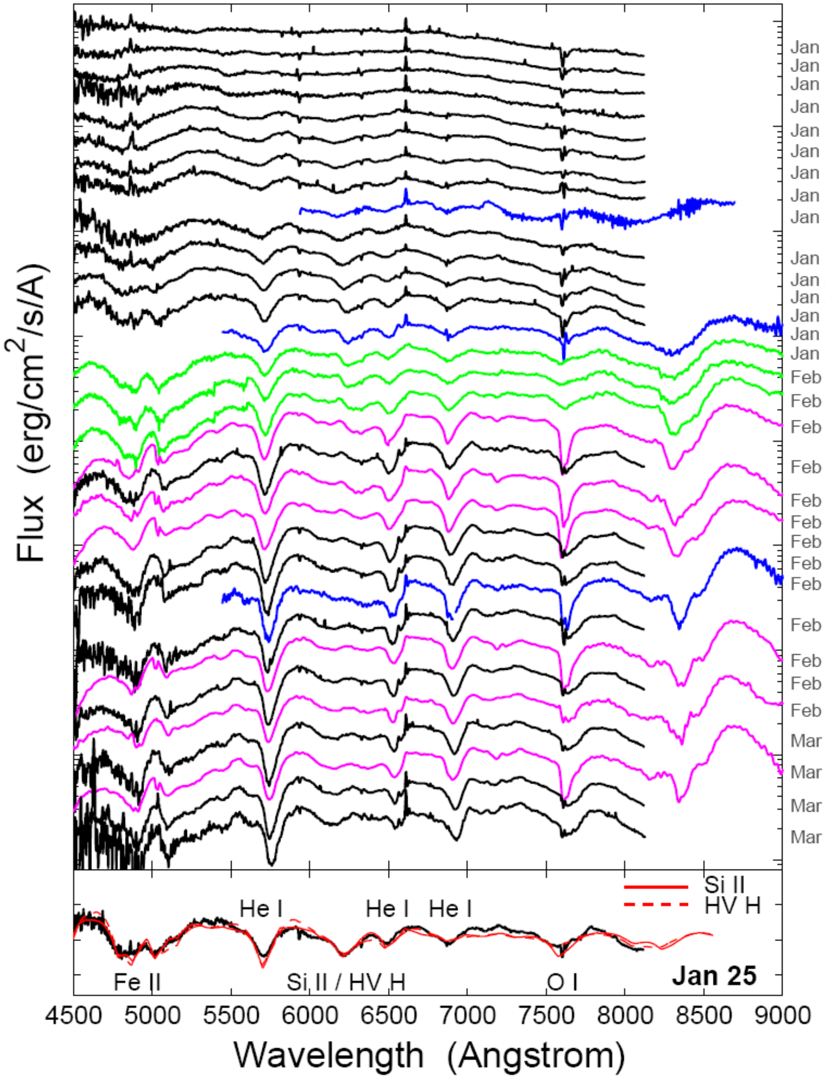


Figure 2. X-ray spectrum of XRO 080109. We use the `xspec` v11.3.2 X-ray spectral fitting package to fit both a power law and a blackbody model to the spectrum. The latter is motivated by the expected spectrum of a shock break-out. In both models we allow for excess neutral hydrogen absorption (N_H) above the Galactic value along the line of sight to NGC 2770, $N_{H,\rm Gal} = 1.7 \times 10^{20}$ cm^{-2}. *Top:* The best-fit power law model ($\chi^2 = 7.5$ for 17 degrees of freedom; probability, $P = 0.98$) has a photon index, $\Gamma = 2.3 \pm 0.3$ (or, $F_\nu \propto \nu^{-1.3\pm0.3}$) and $N_H = 6.9^{+1.8}_{-1.5} \times 10^{21}$ cm^{-2}. *Bottom:* The best-fit blackbody model is described by $kT = 0.71 \pm 0.08$ keV and $N_H = 1.3^{+1.0}_{-0.9} \times 10^{21}$ cm^{-2}. However, this model provides a much poorer fit to the data ($\chi^2 = 26.0$ for 17 degrees of freedom; probability, $P = 0.074$) due to the absence of the expected curvature in the observed spectrum. We therefore adopt the power law model as the best description of the data. The resulting count rate to flux conversion is $1\, rmcountss^{-1} = 5 \times 10^{-11}$ erg cm^{-2} s^{-1}. The outburst undergoes a significant hard-to-soft spectral evolution as indicated by the ratio of counts in the $0.3 - 2$ keV band and $2 - 10$ keV band. The hardness ratio decreases from 1.35 ± 0.15 during the peak of the flare to 0.25 ± 0.10 about 400 s later. In the context of the power law model this spectral softening corresponds to a change from $\Gamma = 1.70 \pm 0.25$ to 3.20 ± 0.35 during the same time interval.

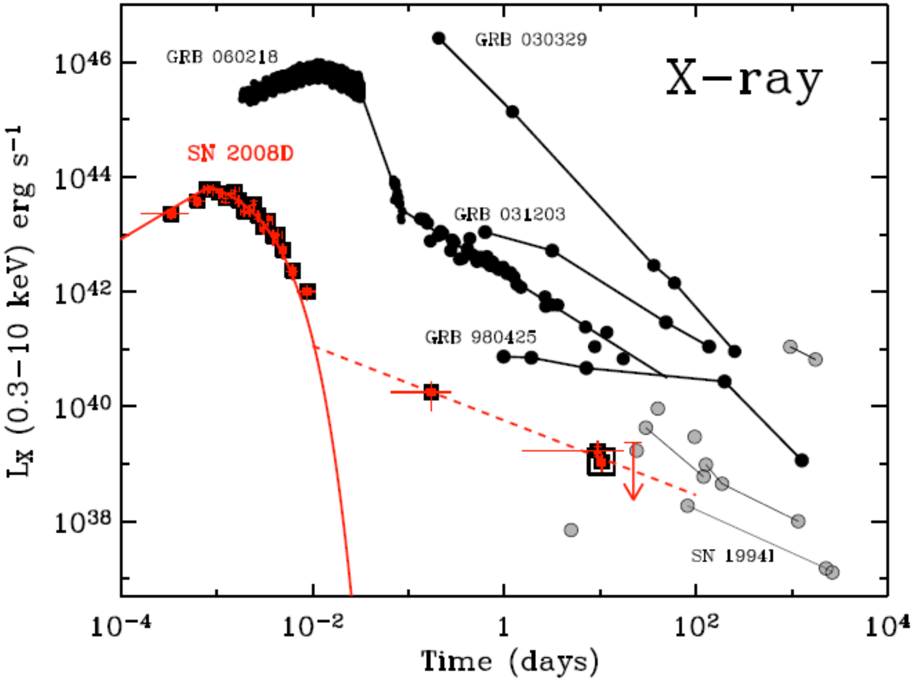
Optical SN—ordinary type Ib SN

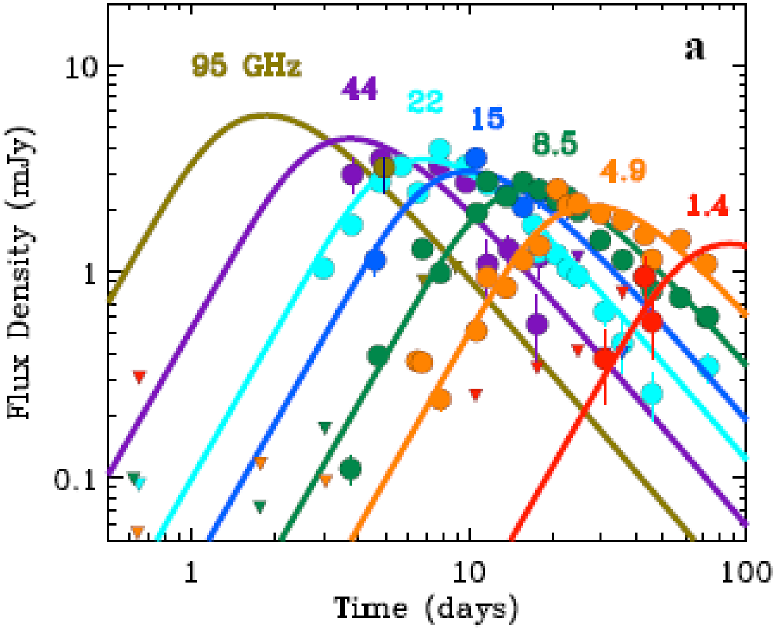
First optical point discovered by Deng, J. & Zhu, Y. 2008 GCN





Ordinary late-time x-ray and radio emission





Shock breakout interpretation

(See however, Xu et al. 2008, Li 2008)

- Thermal emission

Non-detection -> low temperature 3kT<=0.3KeV -> low shock velocity

$$\Gamma\beta = 1\left(\frac{T}{0.1KeV}\right)^{4/3}\left(\frac{E_{th}}{4\times 10^{45}\mathrm{erg}}\right)^{1/6}\gamma_d^{-4/3}$$

$$R_{ph} = 0.5\times 10^{12}\left(\frac{T}{0.1KeV}\right)^{-4/3}\left(\frac{E_{th}}{4\times 10^{45}\mathrm{erg}}\right)^{1/3}\gamma_d^{4/3}\mathrm{cm}$$

- Non-thermal emission

Bulk Comptonization emission

(Wang, Li, Waxman & Meszaros 2007)

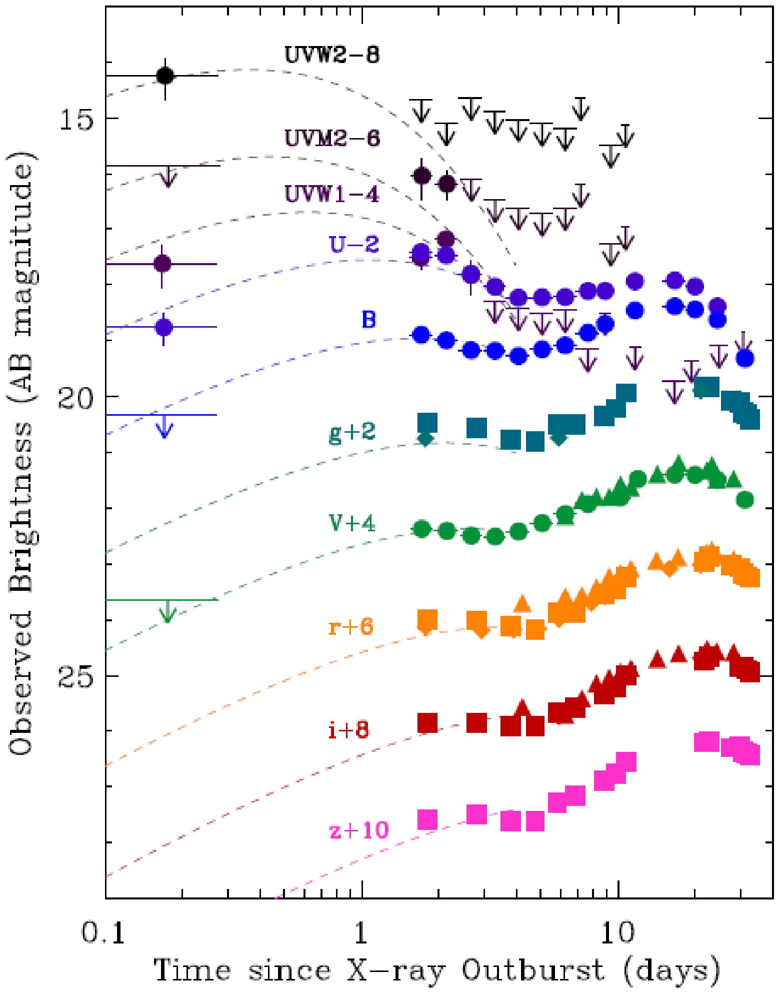
Trans-relativistic shock velocity for type Ib/c

$$v_{f\max} = 13{,}000\left(\frac{\kappa}{0.34\ \mathrm{cm}^2\ \mathrm{g}^{-1}}\right)^{0.13}\left(\frac{\rho_1}{\rho_*}\right)^{-0.086} \times\left(\frac{E_{\mathrm{in}}}{10^{51}\ \mathrm{ergs}}\right)^{0.57}\left(\frac{M_{\mathrm{ej}}}{10\ M_\odot}\right)^{-0.44} \times\left(\frac{R_*}{500\ R_\odot}\right)^{-0.26}\ \mathrm{km\ s^{-1}}\quad\left(n=\frac{3}{2}\right),$$

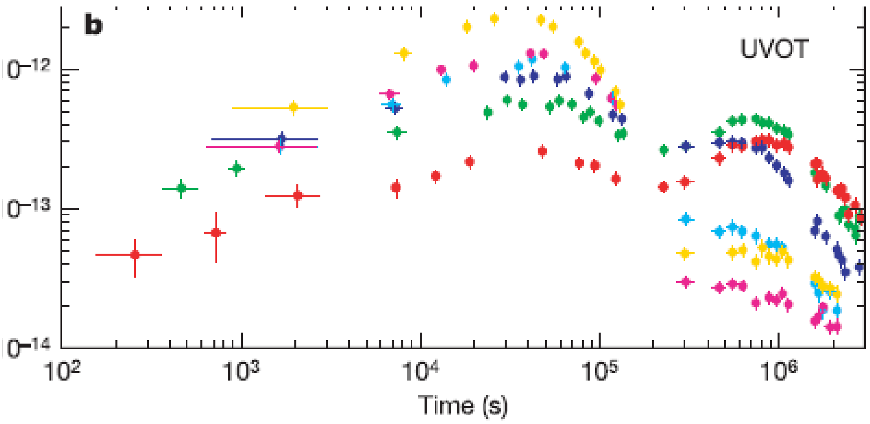
$$v_{f\max} = 33{,}000\left(\frac{\kappa}{0.34\ \mathrm{cm}^2\ \mathrm{g}^{-1}}\right)^{0.16}\left(\frac{\rho_1}{\rho_*}\right)^{-0.054} \times\left(\frac{E_{\mathrm{in}}}{10^{51}\ \mathrm{ergs}}\right)^{0.58}\left(\frac{M_{\mathrm{ej}}}{10\ M_\odot}\right)^{-0.42} \times\left(\frac{R_*}{50\ R_\odot}\right)^{-0.32}\ \mathrm{km\ s^{-1}}\quad(n=3)\ .$$

Similar early optical behavior—cooling of shock heated envelope

SN2008D



SN2006aj



More to be done…

- Only qualitative analysis
- Spectral softening: shock structure, hydrodynamic effect

Summary

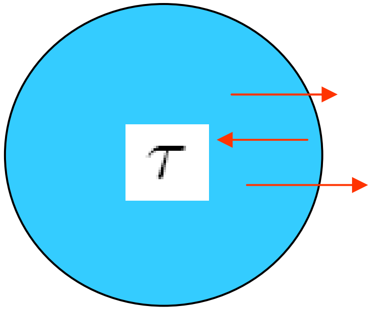
- Long high-luminosity GRBs are due to jets from Collapsars: widely accepted
- Low-luminosity, smooth GRBs not known very well: we suggest they are of hypernova shock breakout origin
- SN Shock breakout detected ? (I believe yes)

Thanks!

Analytic treatment—multiple scattering

Multiple scattering can lead to a power-law spectrum

Consider multiple scattering in a thermal electron plasma with tau<1:



Each scattering: photon energy increased by a factor A

Probability of scattering back τ

Probability of escape $1-\tau$

Some photons undergo k scatterings $\varepsilon_k = \varepsilon_i A^k$

Probability of a photon undergoing k scatterings before escape τ^k

The escaping photon intensity has a power-law shape

$$F(\varepsilon_k) \sim F(\varepsilon_i)\tau^k \sim F(\varepsilon_i)(\varepsilon_k/\varepsilon_i)^{-\alpha}$$
$$\alpha = -\ln\tau/\ln A$$

Pozdnyakov et al. 1976

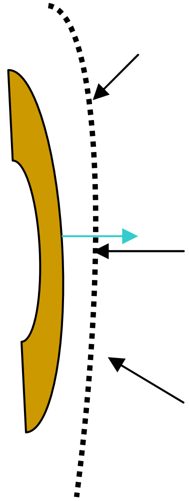
Normal Ib/c SN shock -an X-ray outburst ?

- Radiation-dominated shock

Photon diffusion is the dominant source of dissipation of SN shocks

Not ion-viscosity dissipation

radiation pressure>gas pressure



Shock front